

California Public Utilities Commission  
Safety and Enforcement Division  
Staff Report

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# Survey of Natural Gas Leakage Abatement Best Practices

In partial fulfillment of

Senate Bill 1371 (Leno, 2014) &  
Order Instituting Rulemaking (OIR) 15-01-008

**Charles Magee, P.E.**

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## Introduction

Methane is a greenhouse gas (GHG) at least 20 times more potent than carbon dioxide. Researchers have identified the oil and natural gas industry as a significant source of methane emissions. In California, Senate Bill (SB) 1371 (Leno, 2014) was signed by Governor Brown on September 21, 2014. This bill seeks to reduce methane emissions from leaks in the gas transmission, distribution and storage utilities in California. While the benefits to the environment are apparent, some may question if the economic cost of the legislative mandate will be too high. In actuality, reducing methane emissions may be a win-win resulting in an improved environment as well as a reduction in costs to the consumer.

The California Public Utilities Commission (CPUC) Safety and Enforcement Division (SED) staff prepared this report to comply with the requirements of SB 1371. The bill adds Article 3 (commencing with Section 975) to Chapter 4.5 of Part 1 of Division 1 of the Public Utilities Code which states, in part:

Not later than January 15, 2015, the commission, in consultation with the Air Resources Board, shall commence a proceeding to adopt rules and procedures for those commission-regulated facilities that are intrastate transmission and distribution lines...<sup>1</sup>

Establish and require the use of best practices for leak surveys, patrols, leak survey technology, leak prevention, and leak reduction. The commission shall consider in the development of best practices the quality of materials and equipment.<sup>2</sup>

In January 2015, the CPUC launched Rulemaking (R.) 15-01-008 in response to SB 1371 to investigate new technologies in gas leak detection in the transmission,

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<sup>1</sup> Section 975 (d) at 222. Unless otherwise stated, all statutory references are to the Public Utilities Code.

<sup>2</sup> Section 975 (e)(4) at 223.

distribution and storage process, specifically optimizing for methane reductions.<sup>3</sup> This staff report is written in response to the above statutory requirement and to facilitate record development in R.15-01-008. The purpose of this paper is to identify technologies and practices presently in use around the globe, technologies and practices which are new and/or currently not in use in California, and those which are in various stages of research and development (R&D). We note that this report has identified many different types of leak management technologies and proposes some “best practices”; however, we do not claim to identify ALL technologies or best practices. Leak detection and abatement is an evolving field and there are many technologies currently under development. Consequently, identifying leak management technologies and “best practices” is an ongoing process not ending with the publication of this report and not confined to the work of the Commission. We prepare this report recognizing that all stakeholders, including the utilities and facility operators, have a responsibility to engage in the identification of best practices and an investment in the R&D of new technologies.

In preparing this report, it is not Staff’s intent to suggest that any particular gas leak management technology or practices should necessarily be a requirement subject to further review and evaluation via this instant proceeding. We recognize that there are many variables between the gas transmission, distribution and storage companies including size, location, population density, materials, soil conditions, etc. Thus, the best leak management practice for one company may not be the best for another. We offer this report for consideration by the Commission and parties to R.15-01-008 to inform them of the many gas leak management technologies and practices which may

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<sup>3</sup> See R.15-01-008 “Order Instituting Rulemaking to Adopt Rules and Procedures Governing Commission-Regulated Natural Gas Pipelines and Facilities to Reduce Natural Gas Leakage Consistent with Senate Bill 1371” issued January 22, 2015.

be used to comply with the impending Commission rules and procedures required by SB 1371.

## **Background**

Methane is a potent greenhouse gas that contributes to global warming. As stated in the report “Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries,” by ICF International (ICF Report):

Methane emissions have an enhanced effect on climate change because methane has a climate forcing effect 25 times greater on a 100 year basis than that of carbon dioxide, the primary greenhouse gas (GHG). Methane’s impact is almost three times greater on a 20 year basis and there is research that may cause both factors to be increased. Recent research also suggests that mitigation of short-term climate forcers such as methane is a critical component of a comprehensive response to climate change.<sup>4</sup>

In an effort to reduce methane emissions from gas utilities in California, Senator Mark Leno introduced and Governor Brown signed into law, SB 1371 Natural Gas Leakage Abatement. As stated in SB 1371:

The California Global Warming Solutions Act of 2006 requires the State Air Resources Board to adopt regulations to require the reporting and verification of emissions of greenhouse gases and to monitor and enforce compliance with the reporting and verification program, and requires the state board to adopt a statewide greenhouse gas emissions limit equivalent to the statewide greenhouse gas emissions level in 1990, to be achieved by 2020.

This bill would require the commission, giving priority to safety, reliability, and affordability of service, to adopt rules and procedures governing the operation,

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<sup>4</sup> “Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries, page 2-1, prepared for the Environmental Defense Fund” by ICF International, March 2014.

maintenance, repair, and replacement of those commission-regulated gas pipeline facilities that are intrastate transmission and distribution lines to minimize leaks as a hazard to be mitigated pursuant to the Natural Gas Pipeline Safety Act of 2011, consistent with specified federal regulations, and a specified order of the commission, and to reduce emissions of natural gas from those facilities to the maximum extent feasible in order to advance the state's goals in reducing emissions of greenhouse gases pursuant to the California Global Warming Solutions Act of 2006.<sup>5</sup>

Among other requirements, SB 1371 requires the commission to “establish and require the use of best practices for leak surveys, patrols, leak survey technology, leak prevention, and leak reduction.” This report attempts to identify as many of these current best practices as possible.

The Air Resources Board (ARB) is currently developing a regulation to set greenhouse gas emissions limits for the oil and gas industry in California. The goal of the regulation is to obtain the maximum methane emissions reductions possible from new and existing oil and gas operations in a technically feasible and cost effective manner. By adopting a statewide regulation, ARB seeks to limit the administrative burden to local air districts. ARB staff expects to present the proposed regulation to the Board in September 2015.

The draft regulation, *Greenhouse Gas Emission Controls from Crude Oil and Natural Gas Operations*, applies to onshore and offshore crude oil and natural gas production, processing and storage; natural gas underground storage; and natural gas transmission compressor stations. The draft regulation sets emissions limits and control technology requirements for separator and tank systems, circulation tanks for well stimulation treatment, natural gas compressors, pneumatic pumps, and liquids unloading of

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<sup>5</sup> AB 32, Nunez. Air pollution: greenhouse gases: California Global Warming Solutions Act of 2006.

natural gas well operations. Reporting and record keeping requirements are also specified. Local air districts will implement the regulation by incorporating the requirements into their rules.

With the adoption of the rule, fugitives from storage and transmission compressor stations will be covered, thereby limiting mitigation options. However, annual reporting of activity data is still required to ensure the compliance and effectiveness of the rule.

## **Defining Leaks in the Context of Senate Bill 1371**

SB 1371 changes a paradigm that has existed since the beginning of the gas industry: previously, only leaks considered hazardous to persons or property needed to be repaired immediately. Before the passage of SB 1371, intentional, non-hazardous emissions, during the course of normal operations and maintenance were considered harmless. With SB 1371 now in effect, there is a need to create a new category of hazard in addition to “gas leaks hazardous to persons and property”. That new category is “gas leaks hazardous to the environment”.

In effect, all gas leaks are now considered hazardous.

Although not defined in statute, in considering the new paradigm established by SB 1371, we define a leak as any release of methane from the gas system into the atmosphere, whether intentional or unintentional, whether hazardous or non-hazardous.

We note that this definition of leak is NOT in agreement with the U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (PHMSA) definition of leak, which states:

A “leak” is defined as an unintentional escape of gas from the pipeline. A non-hazardous release that can be eliminated by lubrication, adjustment, or tightening, is not a leak.<sup>6</sup>

The reason for the difference is that PHMSA regulations are concerned with physical safety, while SB 1371 is concerned with reducing methane emissions. SB 1371 uses the words “leaks and leaking components”. Some examples of leaking components are defective gaskets, seals, valve packing, relief valves, pumps, compressors, etc. We also include gas blow-downs during the course of operations, maintenance and testing (including hydro-testing). Therefore, methane emitted during the course of purging, normal operations, maintenance and testing, whether intentional or unintentional, are also considered leaks.

With this definition in place, we now turn to best practices, methods and technologies to reduce methane emissions. Specific topics and major references include the economic analysis of methane leak reduction, leak grading and repair timelines, leak surveys, leak detection, and leak prevention. In this paper we also introduce “administrative” best practices including information management and training. Major references include recent industry technical reports from ICF International, the U.S. Environmental Protection Agency (EPA), and current utility rules, procedures and “best practices.”

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<sup>6</sup> PHMSA Gas Distribution Integrity Management Program Definition

## Economic Analysis of Methane Leak Reduction

Under the current ratemaking practice employed in California, gas distribution utilities do not pay for lost gas due to intentional and unintentional leaks; the gas customers do. Lost and unaccounted-for gas is considered a "cost of doing business" and therefore is passed through to customers via rates. Gas distribution utilities have no financial incentive to eliminate traditionally non-hazardous leaks. While we assume that new investments in capital or costs associated with change in operations to reduce methane from gas leaks should be paid for by customers, we do not take any position on what the appropriate cost sharing or level of reasonableness is appropriate between customers and shareholders. Nor do we take a position on the appropriate CPUC procedural venue to resolve. We do compare customer-oriented costs with the current regime, which is mainly a pass-through model to gas customers for gas used or vented by the utility during normal operations and maintenance, and gas that is lost and unaccounted for. With that in mind, the investment in equipment and infrastructure to reduce methane leaks can be very cost effective for the customers. This economic benefit is noted in the following excerpt from the ICF Report:

Methane is an important climate change forcing greenhouse gas (GHG) with a short-term impact many times greater than carbon dioxide. Methane comprised 9% of U.S. greenhouse gas (GHG) emissions in 2011 according to the U.S. EPA Inventory of U.S. Greenhouse Gas Emission and Sinks: 1990-2011<sup>7</sup>, and would comprise a substantially higher portion based on a shorter timescale measurement. Recent research also suggests that mitigation of short-term climate forcings such as methane is a critical component of a comprehensive response to climate change.<sup>8</sup> Emissions from the oil and gas industry are among the largest anthropogenic sources of U.S. methane emissions. At the same time, there are many ways to reduce emissions of fugitive and vented methane from

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<sup>7</sup> Calculated at a 100 year GWP of 21 – see Section 2.3. of the ICF Report

<sup>8</sup> Shoemaker, J. et. al., "What Role for Short-Lived Climate Pollutants in Mitigation Policy?", Science Vol. 342 13 December 2013.

the oil and gas industry and, because of the value of the gas that is conserved, some of these measures actually save money or have limited net cost.<sup>9</sup>

In Appendix A of this report is an Excel spreadsheet. The first tab of the spreadsheet is titled "Econ. Anal. of CH<sub>4</sub> Reduction". The spreadsheet refers to the ICF Report and contains the cost/benefit of reducing methane leaks from specific components of the entire gas system. For purposes of this report, we focus on the parts of the gas system which are operated by the gas utilities under the jurisdiction of the CPUC, namely gas transmission, storage, distribution and regulated gathering lines as described in 49 CFR 192.8. We do not focus on leaks from the gas system during production, which is under the jurisdiction of the California Air Resources Board (ARB.)

The ICF Report contains data on the total amount of methane leaking from the entire gas system and expresses methane leaks from specific components and equipment as percentages of the total methane leaking from the system. The following table derived from the ICF Report lists some of the most common leaks for gas transmission, storage and distribution systems by component responsible for leakage and percentage of total methane leaked from the gas system. The majority of methane leaked from the gas system does not emanate from "leaks" as they are usually defined, but from gas system equipment and infrastructure. These types of leaks are usually defined by the gas industry as "fugitive emissions". For the purposes of SB 1371, fugitive emissions are now also considered leaks.

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<sup>9</sup> ICF Report, page 1-1

<b>Component Responsible for Leakage</b>	<b>Percentage of Total Methane Leaked from the Gas System<sup>10</sup></b>
Reciprocating Compressors	13%
High Bleed Pneumatic Devices	7%
Local Distribution Company Meters and Regulators	7%
Centrifugal Compressors with wet seals	6%
Gas Engine Exhaust	5%
Intermittent Bleed Pneumatic Devices	5%
Reciprocating Compressor Rod Packing	4%
Pipeline Leaks	2%
Centrifugal Compressors with dry seals	2%
Mains – Plastic	2%
Mains - Cast Iron	2%
Transmission Station Venting	2%
Chemical Injection Pumps	2%
Residential	1%

In April 2009, the California Air Resources Board (ARB) staff conducted a survey of the natural gas transmission and distribution (NG T&D) industry. The information collected was a snapshot of the 2007 activity data, including pipeline length and material, number of compressors stations, types of compressors, number of pneumatic valves, and number of metering and regulating (M&R) stations. In comparing the

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<sup>10</sup> The total percentage does not equal 100% because this a list of the most common (not all) sources of methane leaks in gas transmission, distribution and storage areas of the gas system. This list also does not include the most common sources of methane leaked during the production of gas which, as stated in this report, is under the jurisdiction of ARB.

survey data to national data, ARB staff determined that California has different activity data than other states and therefore has a different breakdown of GHG emissions.

California also has fewer compressor stations compared to oil and gas producing states. However, it has approximately 200,000 miles of distribution pipelines, which is a relatively larger number in comparison. Consequently, pipelines are estimated at approximately 74% of the 2007 GHG emissions. Based on the survey, M&R stations result in about 16% of the emissions and compressor stations and other sources are the remaining 10%. Additional data will improve this estimate.

In addition to information on the sources of methane leaks, the ICF Report also contains the capital cost of purchasing new equipment to reduce methane leaks, the cost of enhanced inspections and other methods to detect and mitigate leaks, and the avoided cost of lost gas from the leaks.

The report also refers to the EPA Natural Gas STAR reference materials for information on how to locate and quantify leaks:

There are a variety of techniques and types of equipment that can be used to locate and quantify these fugitive emissions. Extensive work has been done by EPA and others to document and describe these techniques, both in the Gas STAR reference materials and in several regulatory analyses.<sup>11</sup>

EPA Natural Gas STAR references, techniques and equipment are discussed below in a section entitled "Leak Prevention."

Using the economic analysis in the ICF Report can help the parties in this proceeding to determine the cost/benefit of reducing each type of leak and prioritize how funds should be spent.

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<sup>11</sup> ICF Report at 3-9.

## Leak Grading, and Repair Timelines

It is appropriate to summarize current practices of leak grading and repair timelines since any changes made to optimize methane will need to fit into this existing structure. California gas utilities currently use the following leak grading and repair timelines (with slight deviations between companies):

### **Grade 1 Gas Leaks:**

A Grade 1 gas leak, also referred to as a “hazardous leak,” represents an existing or probable hazard to persons or property and requires immediate repair or continuous action until conditions are no longer hazardous.

### **Grade 2 Gas Leaks:**

A Grade 2 leak is non-hazardous to persons or property at the time of detection but still requires a scheduled repair because it presents a probable future hazard. Grade 2 leaks must be repaired within 15 months. These leaks are usually monitored at set intervals to ensure that they do not get worse or become hazardous before they are scheduled for repair. If they become hazardous, they are upgraded to Grade 1 and should be immediately repaired.

### **Grade 3 Gas Leaks:**

A Grade 3 leak is non-hazardous at the time of detection and can reasonably be expected to remain non-hazardous. These leaks are monitored to ensure that they do not get worse or become hazardous. If they get worse or become hazardous, they are upgraded to Grade 2 or Grade 1.

**Note:** Some smaller California utilities fix all leaks as they are discovered and/or have no open Grade 2 or Grade 3 leaks being monitored.

SB 1371 necessitates changes to the leak grading, and repair timelines because all leaks are now considered hazardous to either people, property or the environment. For example, in the current system a fairly large leak in a remote area may be considered a Grade 3 leak because it is non-hazardous to people or property. Theoretically, it could be allowed to leak indefinitely. With SB 1371 being optimized for methane reduction,

this practice may no longer be appropriate. We offer a suggested update to each grade of leak, below. SB 1371 requires leaks and leak rates to be recorded geographically. We also have highlighted with “XX” variables in which we seek party input. Under this new proposal, we augment the definitions for Grades 1 and 2 leaks and eliminate the Grade 3 category. There may be alternative approaches to this proposal which can be discussed as a topic of conversation at an upcoming workshop.

SB 1371 also suggests that any rules and procedures that may be adopted must not only be guided by SB 1371 “principles” such as “best practices” but also be “technologically feasible” and “cost-effective” and “provide for the repair of leaks as soon as reasonably possible after discovery” – so these factors must be weighed when we consider any options such as the following: <sup>12</sup>

**Grade 1 Gas Leaks**

A Grade 1 gas leak, also referred to as a “hazardous leak,” represents an existing or probable hazard to persons or property, or leaks in excess of XXX thousand cubic feet (Mcf)/week, and requires immediate repair or continuous temporary leak prevention methods until the leak is permanently repaired. Permanent repairs must be completed within XX days. All leaks, including leak rates, shall be recorded and located geographically on GIS or maps. Leak rates shall be monitored XXX thereafter and recorded geographically on a GIS system or maps until the leak is permanently repaired.

**Grade 2 Gas Leaks**

A Grade 2 leak is non-hazardous to persons or property at the time of detection, or leaks less than or equal to XXX Mcf/week. Permanent repairs must be completed within XX days. All leaks, including leak rates, shall be recorded and located geographically on GIS or maps. Leak rates shall be monitored XXX thereafter and recorded geographically on a GIS system or maps until the leak is permanently repaired.

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<sup>12</sup> Section 975 (e)(1) at 222.

The allowable leak rates and times to permanent repairs, represented by XX's above may be considered by the CPUC through the rulemaking process (workshops, and formal stakeholder comments, etc.).

The best practice would be to repair all leaks immediately as they are detected however, for utilities with large service areas that may not be practical or cost effective for small leaks. There may be a positive cost/benefit to allow a brief time limit before Grade 2 leaks have to be permanently repaired. Again, these cost/benefit “tradeoffs” will be further evaluated during the CPUC’s rulemaking process.

## **Leak Surveys**

We recommend as part of the updated leak grading and repair that the scope of leak surveys be enlarged. In order to optimize the reduction of methane, the gas utilities should now perform leak surveys of all gas infrastructure and equipment. That means the entire gas system will now have to be leak surveyed and all fugitive emissions / leaks recorded, graded, tracked and repaired. The ICF Report contains an analysis of the cost and effectiveness of the increased inspections of equipment:

The key factors in the analysis are how much time it takes an inspector to survey each facility, how many inspections are required each year, how much reduction can be achieved, and how much time is required for repairs. Research cited by both Colorado and EPA indicates that more frequent inspections result in greater reductions, summarized as approximately:

- Annual inspection = 40% reduction
- Quarterly inspection = 60% reduction
- Monthly inspection = 80% reduction<sup>13</sup>

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<sup>13</sup> ICF Report at pages 3-10.

Where leaks result from intentional venting, leaking seals, packing, etc. new methods and equipment may be needed to reduce or eliminate the leaks. New methods and equipment are discussed in the "Leak Prevention" section, below.

We expect an increase in leak surveys in the near term, to record, re-grade and repair as many leaks as possible to comply with the rules and procedures resulting from SB 1371. Finding and repairing many gas leaks in a short amount of time may require new methods to perform this task efficiently. One promising method is the use of extremely sensitive mobile leak survey technology combined with using multiple leak repair crews simultaneously to fix all of the leaks in an area in a short amount of time. One such mobile technology in use today by Pacific Gas & Electric (PG&E) is from the Picarro Corporation. The technical name for the Picarro technology is "Cavity Ring-Down Spectroscopy" (see Appendix A "Leak Detection" tab for details). It can detect methane concentrations as low as 1 part per billion (ppb), which is 1000 times more sensitive than many traditional gas detection instruments. The technology allows PG&E to detect gas leaks from 600 feet away; the technology in practice has enabled PG&E to find more leaks in a shorter amount of time.

PG&E has conducted three pilot projects using Picarro technology and sensitive hand held gas detection devices to pinpoint all of the gas leaks within an area. PG&E schedules a date when leak repair crews can be brought to a defined geographic area to fix all of the leaks at once. PG&E calls this the "Super Crew" method. Due to the amount of equipment concentrated in a small area, this method usually requires advanced notifications sent to residents and building occupants. While employing a Super Crew creates a short-term inconvenience, it eliminates the need for individual service calls to repair individual leaks. PG&E estimates that surveying and bundling leak repair work in this way results in a cost savings of approximately 50% compared to

using the traditional leak survey and leak repair methods. In addition, using Picarro technology has allowed the company to complete many more leak surveys than before. Using this technology, PG&E has been able to survey 500 services/ hour vs. 10-11 services/ hour and locate 32 leaks per hour vs. 0.4 leaks/ hour using prior methods.<sup>14</sup> In addition to the benefit of a more rapid reduction in methane escaping to the environment, the leak survey labor cost savings and the methane cost savings can be used to offset new costs, lessening the need for new recovery from customers.

## **Leak Detection**

Gas leak detection is an area where rapid technological advances are being made. We include in this report a list of technologies currently in use, or in R&D, in the U.S. and several different foreign countries. These technologies are listed on the third tab of Appendix A titled "Gas Leak Detection". This is a rapidly evolving field, and any new rules or practices which the CPUC may adopt should be nimble enough to account for technological advancements and refined best practices.

There is no one single "best practice" standard for leak detection – the context of the operator, business situation, geographic location, cost,<sup>15</sup> are all variables. We do list a variety of best available options with the hope that the operator can explore options to

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<sup>14</sup> PG&E presentation to the American Gas Association (AGA), October 5, 2014.

<sup>15</sup> Many of the cost fields on the attached Excel spreadsheet are blank. There are two main reasons for this. The first is that some of the technologies mentioned are still in the R&D phase and are not commercially available yet. The second reason is that many vendors prefer to be contacted by prospective customers to discuss the customer's specific needs before quoting a price. Where the author was able to determine an approximate cost for a device or technology, it was entered on the spreadsheet. The reader should keep in mind however, that the exact cost can change and can only be accurately determined by discussing customer needs with a vendor.

best fit their business situations and to meet the impending rules that the CPUC will be adopting to comply with SB 1371.

SED found leak detection devices, both already in use and in the R&D phase, which we highlight for further consideration by California gas companies. One such “device” isn’t a device at all; it is a dog. Traditionally, dogs have been trained to find and detect explosive materials, drugs and even people. With proper training, as has been done for at least the past 30 years, dogs can be used to find gas leaks. Canines’ sense of smell is sensitive enough to detect gas in the parts per billion (ppb) range, which is on par with the most sensitive gas detection devices in use, or in R&D, today. According to the vendors and research,<sup>16</sup> employing dogs to detect gas leaks can be very cost effective, have a very high accuracy rate and work relatively fast, capable of covering up to five miles per day. Dogs are currently being used to find gas leaks in Texas, Canada and in parts of Europe. At least three companies located in Florida, Canada and Sweden supply these services. We single out detector dogs in this report because we feel that they are a resource which may have been overlooked in California in favor of “high-tech” solutions. However, due to their extremely sensitive sense of smell and relatively rapid speed, we feel that they too deserve consideration by the gas companies.

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<sup>16</sup> “Using canines to inspect for leaks in buried pipelines” by Phil Hopkins, Presented at the 1st Australasian International Welding, Inspection and NDT Conference, iWIN2013. WTIA, Perth, Australia. 10-14th March 2013. Contact Info: E-Mail: p.hopkins@penspen.com, Penspen Limited Unit 7-8, Terrace Level, St Peter's Wharf, St Peter's Basin, Newcastle upon Tyne NE6 1TZ. UK.)

## Leak Prevention

The first step toward the goal of eliminating methane leaks is to determine how most of the methane is currently escaping from the gas system. This understanding should help gas operators re-prioritize new preventative maintenance and inform the scope of modifications needed for their gas system.

To see where the largest methane leaks in the gas system are, we again refer to the ICF Report:

Table 3-2 summarizes the largest emitting source categories in the projected 2018 emissions for the oil and gas sectors by major source category. Due to the lack of specific data on the emission sources for offshore oil and gas production, the study focused on onshore production and offshore emissions are excluded from this list. The top 22 source categories account for 80% of the total 2018 onshore methane emissions of 404 Bcf and the remaining 100+ categories account for 1% or less of the total emissions each. Although these source categories were not included in this analysis due to their small size, there are demonstrated methane reduction technologies that can provide cost-effective reductions for many of them.<sup>17</sup>

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<sup>17</sup> ICF Report at page, 3-6.

Table 3-2 - Highest Emitting Onshore Methane Source Categories in 2018

Source	2018 Emissions (BCF)	Percent of Total	Cumulative Bcf	Cumulative %
Reciprocating Compressor Fugitives	53.8	13%	53.8	13%
High Bleed Pneumatic Devices	28.7	7%	82.5	20%
LDC Meters and Regulators	28.7	7%	111.2	28%
Centrifugal Compressors (wet seals)	24.0	6%	135.3	33%
Gas Engine Exhaust	22.2	5%	157.5	39%
Well Fugitives	20.8	5%	178.3	44%
Reciprocating Compressor Rod Packing	17.6	4%	195.9	48%
Liquids Unloading -Wells w/ Plunger Lifts	13.2	3%	209.1	52%
Intermittent Bleed Pneumatic Devices	13.0	3%	222.1	55%
Kimray Pumps	11.5	3%	233.6	58%
Oil Tanks	11.5	3%	245.1	61%
Flares	9.0	2%	254.1	63%
Stranded Gas Venting from Oil Wells	8.4	2%	262.5	65%
Intermittent Bleed Pneumatic Devices -Dump Valves	7.7	2%	270.2	67%
Oil Well Completions -with Fracturing	6.9	2%	277.1	69%
Pipeline Leaks (All)	6.7	2%	283.8	70%
Pipeline Venting (Transmission)	6.6	2%	290.4	72%
Centrifugal Compressors (dry seals)	6.4	2%	296.8	73%
Mains – Plastic	6.3	2%	303.2	75%
Mains -Cast Iron	6.3	2%	309.4	77%
Transmission Station Venting	6.2	2%	315.7	78%
Chemical Injection Pumps	5.9	1%	321.6	80%
Residential	5.6	1%	327.2	81%
Gathering and Boosting Stations	5.6	1%	332.8	82%

According to the above table, equipment leaks are by far the greatest source of methane emissions from the gas system, with compressor related leaks accounting for 25% of all methane leaked into the atmosphere. More than 22% of total methane leaks are related to oil and gas production, which is beyond the scope of SB 1371.

The ICF Report and the EPA Report complement one another. The economic analysis report by ICF approaches the methane leaks from the gas system on a macro scale, analyzing the environmental impact of the leaks, identifying the sources and analyzing the cost of eliminating the leaks. It also identifies the equipment that leak the largest amount of methane and describes in detail the corrective actions to eliminate or

reduce the leaks. For example, as mentioned earlier, compressor related leaks are the largest source of leaks. The economic analysis report by ICF describes the problematic issues with compressors and the corrective actions needed to reduce the leaks. Using information found in the EPA Report such as labor rates and equipment cost, ICF calculates the time required to recover the investment to replace or repair equipment to reduce or eliminate the largest gas leaks. The report's analysis also recalculates this payback time using various prices of natural gas. The economic analysis report by ICF addresses the corrective actions needed to mitigate, cost-effectively, approximately 80% of the methane leaks from the gas system.

#### The EPA Natural Gas STAR Program

The second tab of Appendix A contains a link to the EPA Natural Gas STAR program (EPA Report). The EPA Report identifies additional specific corrective actions to reduce methane leaks from almost 100% of the sources of gas leaks. The EPA Report examines practices such as replacing methane-driven pumps with electric motor-driven pumps, replacing pneumatic controls with mechanical controls, changing compressor seals from wet seals to dry seals, better inspection and maintenance practices for various types of equipment, ways to reduce equipment start-ups to reduce methane emissions, flexible liners for gas mains, ways to reduce gas venting and much more. The EPA Report describes a method used by Open Grid Europe which uses a mobile compressor truck to pump down and transfer methane from gas lines instead of venting them to the atmosphere. The EPA Report also includes the investment capital required for repairs or new equipment, along with an analysis of the time needed to recover the investment at various prices of natural gas.

The EPA also hosts regional workshops to help gas companies learn how to reduce methane emissions. As the EPA Report states:

The Natural Gas STAR Program hosts regional Technology Transfer Workshops for each sector of the natural gas industry. These workshops provide a forum for oil and natural gas companies to receive and share detailed information about current cost-effective technologies and practices to reduce methane emissions in their specific sector. Technical presentations provide current information about the emission reducing technologies and practices covered at the Technology Transfer Workshops.<sup>18</sup>

Almost all of the corrective actions described in both the ICF and the EPA reports require only one to three years, sometimes less, to save enough gas to recover the investment in new equipment or modifications necessary to eliminate or mitigate gas leaks.<sup>19</sup> The savings from the corrective actions only account for the dollar value of the natural gas lost and do not monetize the benefit to the environment.

### Gas Leak Prevention

The fourth tab of Appendix A lists the technologies and practices mainly used to prevent transmission and distribution piping leaks as opposed to leaks due to equipment, operation and maintenance. The information in this tab includes new pipe lining techniques, advanced pipe inspection devices and an acoustic warning system to alert pipeline owners when there is third-party activity near their pipeline.

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<sup>18</sup> EPA Report at: <http://www.epa.gov/gasstar/workshops/index.html>

<sup>19</sup> This is for \$3/Mcf natural gas which, in recent history, is inexpensive gas. If gas prices rise higher, the payback time is even less.

## **Information Management**

The fifth tab of Appendix A is titled, "Information Management". It contains information on some of the latest hand-held devices used by leak surveyors to record leak information by GPS coordinates and to aid them on their surveying route. The devices can be programmed to contain information such as on-the-job dangers at particular residences (e.g. dogs), the location of gas services, statistics, templates for recording the material condition of the gas services, reporting and grading leaks and more. The information can then be uploaded to the utility's main leak tracking program and used to generate work orders to repair leaks. Using devices such as this reduce transcription errors and incomplete or illegible records.

This tab also contains information on two of the main information management systems in use today, Maximo by IBM and SAP Enterprise Asset Management. These systems are used to track leak information, schedule work and generate work orders. In order to effectively manage the new definitions of gas leaks proposed above, robust information management systems are critical. to enable information to flow accurately and efficiently between the field and work planners, engineering, management and other affected departments.

## **Training**

Training is extremely important for operator safety and the proper use of any of the technologies and devices described in this report. Accurate gas leak detection and measurement can only be obtained if the operator understands the limitations of the technology and devices that he/she is using. There are variables which can affect the accuracy of measurements such as wind speed, distance from the leak, obstructions,

fog, rain, reflective backgrounds, etc. In addition, some of the instruments require more frequent calibration than others and some use highly pressurized flammable gas, which can be dangerous. For these reasons, gas companies should formalize and document training programs for the operators of these devices. The training programs should include the following elements:

- Scheduled training for all operators;
- Qualification testing to ensure that operators are able to
  - operate the equipment properly and safely,
  - calibrate equipment, if necessary,
  - demonstrate that they can detect measure and record gas leaks accurately;
- Requalification training should occur at least annually;
- Requalification training should also occur before an operator can use any equipment that he/she has not used within the past 60 days;
- All training records should be retained for a period of time in accordance with GO 112 and any applicable CFRs.

## **Records**

An appropriate record retention policy will be determined in consultation with the California Air Resources Board and stakeholders during the course of this proceeding.

## Recommendations

Based on the preliminary staff observations made throughout this report, SED staff offers the following recommendations to meet the requirements of SB 1371 and preliminary scoping memo objectives:<sup>20</sup>

1. The Commission should ensure that financial incentives are properly aligned for both customers and shareholders in the gas transmission, distribution and storage (GTD&S) corporations to eliminate **both** intentional and unintentional methane leaks from the gas system. After assessing ratemaking implications of potential performance based incentives, the Commission should consider the appropriate procedural venue to implement them (e.g., General Rate Case, Gas Cost Incentive Mechanism).
2. The Commission, in cooperation with the parties to R.15-01-008, should develop a new methane leak grading system which meets the intent of SB 1371. Staff proposes updated definitions for Grades 1 and 2 leaks, and eliminating Grade 3. Staff suggests hosting a workshop to determine if there are alternatives to this approach and to build consensus regarding any preferred alternative.
3. The Commission should evaluate the operations, maintenance, and repair practices to determine whether existing (and newly proposed) practices are effective at reducing methane leaks.<sup>21</sup>

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<sup>20</sup> R.15-01-008 at 12. Final scoping memo objectives will be determined following a Prehearing Conference for this proceeding at a later date.

<sup>21</sup> Section 975 (e)(3).

4. The Commission should consider how to best have the GTD&S corporations to enlarge the scope of their leak surveys and procedures to include their entire gas system including all equipment and facilities.
5. The Commission should consider how to best encourage the GTD&S corporations to invest in the leak detection equipment for their business and to continually search for best practices in leak detection and prevention.
6. The Commission should consider how the GTD&S corporations should implement training programs as described in this report to ensure that personnel are proficient in the use of leak survey equipment and are periodically re-tested and re-qualified to use it.
7. The Commission should consider how the GTD&S corporations should develop capital improvement plans to upgrade their systems with equipment and modifications which have been identified as best practices for the prevention of methane leaks. These expenditures should be considered in the GTD&S General Rate Case or separate application.
8. The Commission should establish the specific requirements for the annual reports required by SB 1371.

## **Conclusion**

In this report, staff provides references to an economic analysis of methane emission reductions conducted by ICF International. The report also includes references to best leak prevention equipment and methods researched by the EPA and references to some of the newest equipment in the field of gas leak detection. The report also describes a framework for a new leak grading system which would comply

with SB 1371. The reports claim that methane leak reduction is both beneficial to the environment and cost effective to the ratepayer. If an effective methane reduction program is implemented, the ratepayer may no longer be required to pay for methane which leaks from the gas system and the gas system should be safer due to the identification and elimination of more gas leaks. The short one-to-three-year payback time to the ratepayer for most of the new equipment and modifications needed by the utilities appears promising.

## Appendix A - Natural Gas Leakage Abatement Best Practices

# **Economic Analysis of Methane Emission Reduction Opportunities in the U.S. Onshore Oil and Natural Gas Industries**

3/1/2014

Prepared for

Environmental Defense Fund

257 Park Avenue South

New York, NY 10010

Prepared by

ICF International

9300 Lee Highway

Fairfax, VA 22031

Environmental Protection Agency (EPA)

Recommended Technologies and Practices

**The following report is a valuable source of information to help determine where the greatest opportunities are for Methane reduction in the Gas Industry.**

[http://www.edf.org/sites/default/files/methane\\_cost\\_curve\\_report.pdf](http://www.edf.org/sites/default/files/methane_cost_curve_report.pdf)

# Appendix A - Natural Gas Leakage Abatement Best Practices

## Environmental Protection Agency (EPA) Recommended Technologies and Practices

Natural Gas STAR partners share information on cost-effective methane emission reduction technologies and practices via submission of annual progress reports detailing their emissions reduction activities. To promote technology transfer and share industry best practices, the Natural Gas STAR Program provides information on cost-effective methane emission reduction opportunities through a variety of documents including *Lessons Learned Studies*, *Partner Reported Opportunities (PRO) Fact Sheets*, Technical Presentations, and *Partner Update* articles (to learn more, see descriptions of Natural Gas STAR technical resources below). *Lessons Learned Studies* and *PRO Fact Sheets* are also available in Arabic, Chinese, Russian, and Spanish translations.

The following webpages are extremely valuable sources of information for the practical, cost-effective reduction of methane emissions in the natural gas industry:

### [Recommended Technologies and Practices](#)

[Technical Document Translations](#)

[Program Forms](#)

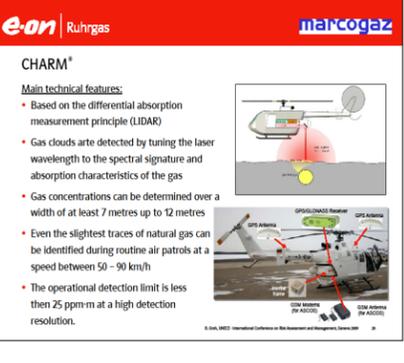
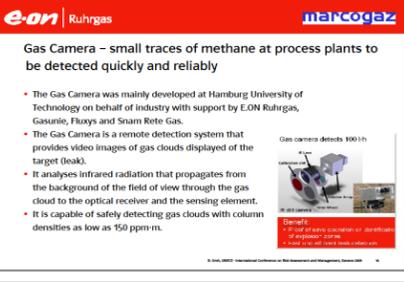
[Technology Transfer Workshops](#)

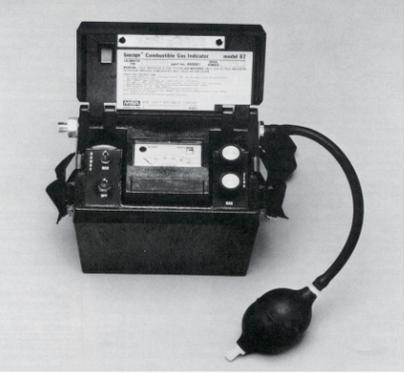
[Service Provider Directory](#)

[Natural Gas STAR Contacts](#)

Appendix A - Natural Gas Leakage Abatement Best Practices

Gas Leak Detection Technology

Name	Technology	Uses	Detection Sensitivity	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files	Utility Company	Location	
Picarro	Cavity Ring-Down Spectroscopy (CRDS) - Nearly every small gas-phase molecule (e.g., CO <sub>2</sub> , H <sub>2</sub> O, H <sub>2</sub> S, NH <sub>3</sub> ) has a unique near-infrared absorption spectrum. At sub-atmospheric pressure, this consists of a series of narrow, well-resolved, sharp lines, each at a characteristic wavelength. Because these lines are well-spaced and their wavelength is well-known, the concentration of any species can be determined by measuring the strength of this absorption, i.e. the height of a specific absorption peak. But, in conventional infrared spectrometers, trace gases provide far too little absorption to measure, typically limiting sensitivity to the parts per million at best. CRDS - Cavity Ring-Down Spectroscopy - avoids this sensitivity limitation by using an effective pathlength of many kilometers. It enables gases to be monitored in seconds or less at the parts per billion level, and some gases at the parts per trillion level. (Source: Picarro website)	The unit is mounted on a vehicle and driven through neighborhoods to identify areas where methane is detected. (Source: Picarro website)	It enables gases to be monitored in seconds or less at the parts per billion level, and some gases at the parts per trillion level. It can 1 PPB detect up to 600' from the source. (Source: Picarro website)	<a href="http://www.picarro.com/">http://www.picarro.com/</a>	Must contact the vendor	The Picarro Surveyor enables operators to survey gas secured mains and services at traffic speeds and automatically map and display results in real-time on a secure web browser. The user also has the option to perform a real-time analysis to distinguish between natural gas and other biogenic sources. The data is transferred stored, processed and mapped in the Picarro Processing Platform (P-Cubed). Picarro is able to locate and pinpoint leaks under varying environmental conditions, provide more efficient surveys to streamline operations and repairs, remove human error in reporting and provide a data-driven audit trail. Generates verifiable, traceable and complete records. (Source: Picarro website)	Results can be affected by weather, especially wind.	<a href="http://www.picarrosurveyor.com/">http://www.picarrosurveyor.com/</a>	PG&E	California	
CHARM® – CH4 Air Remote Monitoring, i.e. helicopter-borne infrared laser-based (LIDAR) remote gas detection system	How does CHARM® work?  Natural gas traces made visible; Detection of very low methane concentrations  Natural gas detection systems used for monitoring the tightness of buried pipelines must be capable of identifying even the smallest traces of methane.  The measurement method of CHARM® is based on the absorption of specific infrared light wavelengths by methane, the main constituent of natural gas. CHARM® generates two short infrared laser pulses, whose wavelength is adjusted such that the first pulse is absorbed by methane while the second pulse is not absorbed. A small amount of the light of both pulses is scattered back to the measurement system where it is focussed by a telescope onto a sensitive detector. Evaluating the ratio of the measured signal of both pulses directly gives the concentration of the methane layer.  For more technology information refer to this link: <a href="http://www.open-grid-europe.com/cps/rde/kchg/open-grid-europe-internet-hs.xsl/1222.htm">http://www.open-grid-europe.com/cps/rde/kchg/open-grid-europe-internet-hs.xsl/1222.htm</a>	CHARMS hardware is mounted on a helicopter to survey the gas piping system. The use of CHARM requires not only the hardware (helicopter, system), but also a detailed data analysis depending on the customer requirements. This is a service offered by Adlares GmbH of Teltow, Germany. It is able to inspect up to 350 km/day. Their service will be possibly available in North America in 2016. Since this is a contractual service, the pipeline operator does not need to employ CHARM-specialists.	Gas concentrations can be determined over a width of at least 7 metres up to 12 metres Even the slightest traces of natural gas can be identified during routine air patrols at a speed between 50 – 90 km/h at altitudes between 80 m and 140 m. It can detect a leak of 100 liter/hour (0.06 scfm) at wind speeds of 3 m/s (6,7 mph). Even at 6 m/s (13 mph) it can detect leakages of 500 l/h (0,3 scfm). The operational detection limit is less than 25 ppm-m at a high detection resolution. (Source: E-ON/RuhrGas and Open Grid Europe)	<a href="http://www.open-grid-europe.com/cps/rde/kchg/open-grid-europe-internet-hs.xsl/1222.htm">http://www.open-grid-europe.com/cps/rde/kchg/open-grid-europe-internet-hs.xsl/1222.htm</a>	This is a service offered by Adlares GmbH, in partnership with Open Grid Europe. Currently, it is not available in the US but the company anticipates that it will begin to offer the service to North America in 2016. The pricing for the CHARM survey depends on many parameters, including Topology (structure) of the pipeline (straight ahead, many branches, ...), Assigned mileage, Preparation costs (e.g. transfer from base to area of operation). Assigned additional services (e.g. photographic mapping) (Source: Matthias Ulbricht of Adlares GmbH)	What can CHARM® perform? Efficient and reliable pipeline inspections from the air.  The CHARM® system, developed by Open Grid Europe, is a highly efficient innovative procedure of monitoring natural gas grids. Because of the high sensitivity of the system as well as the automatically and extremely precisely beam control (autotracking), CHARM® can be reliably used even for complex pipeline topologies.  Key facts and benefits at a glance Helicopter-borne infrared-based laser remote gas detection system Detection of slightest traces of natural gas (at altitudes between 80 m and 140 m) Recognized under DVGW codes of practice (Technical Rule G 501: Airborne Remote Gas Detection Methods) Operational detection limit < 25 ppm•m Automated documentation of pipeline inspection and real-time reporting of incidents High efficiency in monitoring pipelines in built-up areas Area-wide inspection of pipeline route (7 m up to 12 m) Accurate geographic positioning with CHARM®-Autotracking (CAT) 100 double pulse measurements per second Patrol speed 50 km/h (up to 90 km/h) (Source: Open Grid Europe). No capital investment. This is a contracted service provided by Adlares GmbH of Teltow, Germany, which is in partnership with Open Grid Europe. (Source: Matthias Ulbricht of Adlares GmbH) See also Presentations and Useful Files to the right.	It cannot detect gas unless it is able to leak to the surface. It is currently unavailable in the US. It is scheduled to be available in North America in 2016.	 A research partnership with ITT led to integration and demonstration of GIS imagery, Midwave Infra-red cameras and Differential Absorption Lidar and resulted in near real-time data collection and processing improving from 3-4 weeks to one day. At the conclusion of this research, Route Generation can now be accomplished in the field and requires only 1 hour of effort to generate 100 miles of pipeline routes. This is a 30X improvement in speed. (Source: Government & Industry Pipeline Research and Development (R&D) Forum, Event Summary Report, Westin Arlington Gateway, Arlington, VA, July 18-19, 2012) See the entire presentation here: <a href="http://primis.phmsa.dot.gov/rd/mtg_071812.htm">http://primis.phmsa.dot.gov/rd/mtg_071812.htm</a>	Open Grid Europe and E-ON/RuhrGas(Europe)	E-On Ruhrgas and numerous others / Europe	
Gas Camera	The Gas Camera was mainly developed at Hamburg University of Technology on behalf of industry with support by E.ON Ruhrgas, Gasunie, Fluxys and Snam Rete Gas. The Gas Camera is a remote detection system that provides video images of gas clouds displayed of the target (leak). It analyses infrared radiation that propagates from the background of the field of view through the gas cloud to the optical receiver and the sensing element. There are IR Gas Cameras sold by other vendors.	Can be a portable camera used to scan facilities or a stationary camera aimed at a gas facility or other target which can alarm if a methane leak is detected.	It is capable of safely detecting gas clouds with column densities as low as 150 ppm-m. (Source:Eon Ruhrgas)	<a href="http://www.tuhh.de/mt/tir/project09.htm">http://www.tuhh.de/mt/tir/project09.htm</a>	N/A	Detect gas at a safe distance. Can scan large areas quickly. Can provide video images of gas clouds	Obstacles in the line of sight.	 The Gas Camera was mainly developed at Hamburg University of Technology on behalf of industry with support by E.ON Ruhrgas, Gasunie, Fluxys and Snam Rete Gas. The Gas Camera is a remote detection system that provides video images of gas clouds displayed of the target (leak). It analyses infrared radiation that propagates from the background of the field of view through the gas cloud to the optical receiver and the sensing element. It is capable of safely detecting gas clouds with column densities as low as 150 ppm-m.	Open Grid Europe and E-ON/RuhrGas(Europe)	E-On Ruhrgas and numerous others / Europe	
EyeGas by Opgal	Gases have their own characteristic absorption lines in the IR spectrum. The use of a gas camera, with an appropriate sensitivity, allows gases to be visualized. Thermal imagers are sensitive to the absorption lines spectrum and are designed to have an optical path sensitivity in correspondence with the gases, in the spectrum area of interest. When the operating gas camera is pointed at leaking components, the emissions will absorb the IR energy, appearing as what looks like smoke on either a black or white background. (Source: Opgal Corp)	Portable camera about the size of a normal video camera allow the operator to see and record gas leaks. (Source: Opgal Corp)	Only says that it can detect small leaks.	<a href="http://www.opgal.com/">http://www.opgal.com/</a>	Must contact the vendor	Detect gas at a safe distance. Can scan large areas quickly. Specially designed for the natural gas, oil and petrochemical industries, taking into consideration the requirements of the users. Very sensitive and detects smaller leaks than the existing optical imagers' portable solutions. Certified for use in hazardous environments (Class 1, Div.2 and ATEX II), allowing inspection at hazardous places in plants. Implements an internal video and audio recording device. Features a large color LCD display for image and text display. Rugged and durable by design to be used as a tool in the field. It's a portable camera about the size of a normal video camera allow the operator to see gas leaks. The camera also can record videos and audios of the leak and allow you to add commentary. Only requires 1 hour of training. (Source: Opgal Corp)	Obstacles in the line of sight.	<a href="http://www.youtube.com/watch?v=TD6p9cAwXQg">http://www.youtube.com/watch?v=TD6p9cAwXQg</a>	<a href="http://www.opgal.com/ABOUTUS/Overview.aspx">http://www.opgal.com/ABOUTUS/Overview.aspx</a>	Not Known	Location of the company appears to be Israel
GasFindIR by FLIR	Specifically the FLIR GF 320 can be used to detect Methane and Volatile Organic Compounds (VOCs) by visually displaying the temperature of the escaping gas and surroundings on a video screen. It can make small differences in temperature visible. See the links to the right.	Portable camera about the size of a normal video camera allow the operator to see and record gas leaks. (Source: FLIR)	8g/hr	<a href="http://www.flir.com/thermography/americas/us/view?id=30866">http://www.flir.com/thermography/americas/us/view?id=30866</a>	Must contact the vendor	Detect gas at a safe distance. Can scan large areas quickly. The FLIR GF320 is an IR camera for optical gas imaging (OGI) that visualizes and pinpoints leaks of VOCs, without the need to shut down the operation. The portable camera also greatly improves operator safety, by detecting emissions at a safe distance, and helps to protect the environment by tracing leaks of environmentally harmful gases. The GF320 is used in industrial settings such as oil refineries, natural gas processing plants, offshore platforms, chemical/petrochemical industries, and biogas and power generation plants.  Can also be used to detect leaks in residential gas distribution piping. It's a video camera with IR capability. It can record videos or still pictures. Has GIS capability so you know the exact location of the leak. Optical gas imaging is an accepted leak detection technique in the Method 21 Leak Detection and Repair Alternative Work Practice (Method21 AWP) as well as the Green House Gas Reporting Rule.	Obstacles in the line of sight.	<a href="http://www.flir.com/cs/emea/en/view?id=41384">http://www.flir.com/cs/emea/en/view?id=41384</a>	<a href="http://www.flir.com/cs/emea/en/view?id=41529">http://www.flir.com/cs/emea/en/view?id=41529</a>	Unknown	FLIR is a worldwide company. Headquarters appear to be in Europe.
Optical Methane Detector	The vehicle mounted Optical Methane Detector *TM uses infra-red technology to specifically detect methane gas leaks down to levels of 1ppm without cross interference to other hydrocarbons. (Gas Measurement Instruments LTD.) The Optical Methane Detector's infrared light source is mounted on a crossbar at one side of a vehicle's front bumper and then aimed at an optical detector mounted at the other end of the bumper. When methane molecules pass between the source and the detector, they absorb energy from the light beam, resulting in an attenuation of the beam that is proportional to the amount of gas present. This attenuation affects the detector's reading and the driver is alerted to a leak. The concentration may then be observed, mapped and logged. The Optical Methane Detector is effective at detecting trace levels as low as 1 ppm of methane. Because only part of the infrared light beam is affected by partial obstruction of the light path (such as from deposits of dirt on the exterior or water) the unit can function in light rain and other non-ideal survey conditions. (Source: Lechtzer Inc.)	Mobile Leak Survey - Attaches to front of truck - Speeds up to 35 miles per hour. (Source: Consumer's Energy Presentation to AGA - 2011)	Range of 16' and detects down to 1ppm and < 1 second (Source: Consumer's Energy Presentation to AGA - 2011, Gas Measurement Instruments LTD and Lechtzer Inc. and Heath Corp.)	<a href="http://heathus.com/products/omd/">http://heathus.com/products/omd/</a>	Must contact the vendor	Infrared technology, methane specific, instant response, very high survey speeds (to 50 kph), largely unaffected by rain or surface water, no pumps or calibration gases, GPS option (Gas Measurement Instruments LTD.)	Open path detectors suffer downtime from anything that blocks the path of the beam, such as people, vehicles or thick fog. (Source: Wikipedia)	<a href="http://heathus.com/wp-content/uploads/omd.pdf">http://heathus.com/wp-content/uploads/omd.pdf</a>	Consumer's Energy, PG&E	Michigan, California	

Name	Technology	Uses	Detection Sensitivity	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files	Utility Company	Location
Heath Detecto Pak Infrared (DP-IR)	Infrared Controlled Interference Polarization Spectrometer. The HEATH Detecto Pak-Infrared (DP-IR™) is a highly advanced technology capable of detecting methane without false alarming on other gases. The DP-IR is the latest of a new generation of leak survey instruments from HEATH that will greatly improve the productivity and safety of a walking/mobile survey. The DP-IR functions by using an infrared optical gas detection system. <b>This instrument is intended to replace the current surveying equipment using the traditional Flame Ionization with next generation technology utilizing a simple light beam, eliminating the need for expensive gas cylinders and refill systems.</b> It is designed to be selective to detecting methane only, and will not false alarm on other hydrocarbon gases. (Source: Heath Corp.)	Walking leak survey. According to Heath, the manufacturer, you use it the same way as the Flame Ionization Detector. (Source: Heath Corp.)	0-1000 PPM: 1 PPM 1000-10,000 PPM: 5 PPM 1-100%Gas: 0.5%. For more information see the brochure: <a href="http://heathus.com/wp-content/uploads/dpir.pdf">http://heathus.com/wp-content/uploads/dpir.pdf</a>	<a href="http://heathus.com/product_category/gas/infrared-optical-based/">http://heathus.com/product_category/gas/infrared-optical-based/</a>	Must contact the vendor	The DP-IR operates under a variety of environmental conditions including cold or hot weather. Its rugged design will stand up to normal field use and operating conditions. The DP-IR has built-in Self-test and Zero functions that will assure that the instrument is operating properly. Using the internal calibration cell, the operator can perform the self-test as part of a daily start up routine. While in operation, the DP-IR continuously monitors several parameters to ensure that the instrument is functioning properly. Should any of these parameters go outside of the operational limits, an audible alarm will sound and a Fault/Warning error message will be displayed. (Source: Heath Corp.)	Cannot be used at a distance. Gas has to be sucked into the machine to be analyzed.	<a href="http://gasandoil.com.au/2013/01/17/heath-detecto-pak-infrared-dp-ir/">http://gasandoil.com.au/2013/01/17/heath-detecto-pak-infrared-dp-ir/</a> <a href="http://undergroundconstructionmagazine.com/heath-consultants-detecto-pak-infrared">http://undergroundconstructionmagazine.com/heath-consultants-detecto-pak-infrared</a>	PG&E, Alpine, Sempra, West Coast Gas	California
Remote Methane Leak Detector	The RMLD-IS does not have to be within the gas plume because it uses laser technology known as Tunable Diode Laser Absorption Spectroscopy. As the laser passes through a gas plume, the methane absorbs a portion of the light, which the RMLD-IS then detects. This technology makes it possible to detect leaks along the sight line without always having to walk the full length of the service line. (Source: Heath Consultants website)	Walking Leak Survey. Can be used from 15' to 100' away. Must have appropriate background target to reflect the IR beam (i.e. ground or building) Scan slowly over longer distances Avoid dark zones (Source: Consumer's Energy Presentation to AGA - 2011)	According to NYSearch it can detect 5 ppm from a distance of 200 feet. <a href="http://www.nysearch.org/commercial_products.php">http://www.nysearch.org/commercial_products.php</a> Can be used from 15' to 100' away. Must have appropriate background target to reflect the IR beam (i.e. ground or building) (Source: Consumer's Energy Presentation to AGA - 2011)	<a href="http://heathus.com/product_category/gas/laser-based/">http://heathus.com/product_category/gas/laser-based/</a>	Must contact the vendor	Works well in outdoor situations. (Source: Wikipedia) Using laser technology, remote detection allows you to safely survey areas that may be difficult to reach such as busy roadways, yards with large dogs, fenced-off areas and other hard-to-access places. Will only detect Methane, not other hydrocarbon gases (Heath Consultants website)	Open path detectors suffer downtime from anything that blocks the path of the beam, such as people, vehicles or thick fog. (Source: Wikipedia)	<a href="http://www.nysearch.org/commercial_products.php">http://www.nysearch.org/commercial_products.php</a>	Consumers Energy - Michigan, PG&E, Sempra, Dominion East - Ohio	Ohio, Michigan, California
Laser Methane Detector by Gazomat	The INSPECTRA® Laser is a natural gas leak portable analyser with laser spectroscopy. The measuring chamber of the INSPECTRA® Laser analyzer is fitted with a laser diode adjusted to the absorption wavelength specific to methane. In the presence of methane molecules, the laser beam is partially absorbed. Thus, only methane is detected. The device is insensitive to other hydrocarbon gases, chemicals, water vapours and pollution that may be present in the atmosphere. (Source: Gazomat Corp.)	Walking Leak Surveys • ATEX Version: for use in explosive atmospheres (both inside and outside of buildings), suitable for any application requiring the measurement of natural gas concentrations (methane only) such as : • Survey of natural gas network (methane only) • Detection and localization of gas leaks (methane only) • Monitoring of natural gas compression plants • Monitoring of methanation plants • Monitoring of landfills • Measurements in laboratories, etc. • Non ATEX version : for use outside of buildings only and exclusively limited to NON ATEX areas presenting no risk of permanent presence of explosive gases. • Applications requiring natural gas concentration measurements (methane only). (Source: Gazomat Corp.)	Sensitivity of 1 ppm (Source: Gazomat Corp.)	<a href="http://www.gazomat.com/Pages/INSPECTRA-Laser-Portable.aspx?language=English">http://www.gazomat.com/Pages/INSPECTRA-Laser-Portable.aspx?language=English</a>	Must contact the vendor	Small, portable, weighs 6 lbs. 2 measurement scales: • PPM scale from 0 ppm to 10,000 ppm • GAS scale: from 0 % to 100 % volume gas • Simultaneous display of double measurement range • Very short response time • Two sampling speeds: 35 l/hour and 70 l/hour. GPS Tablet system for total traceability of on-foot inspections. This device enables the operator to keep a computerized record of his/her detection operations: • Geographical positioning on a map of detected leak indications • Recording of concentration measurements • The operator may insert comments during the on-foot inspection • Inspection reports are generated (location, date and time, leak numbers, concentrations, weather conditions and operator comments). See the Gazomat website link for more information. (Source: Gazomat Corp.)	The probe must come in contact with the gas to sniff it. Not for locating gas leaks from a distance.	<a href="http://www.gazomat.com/?language=English">http://www.gazomat.com/?language=English</a>	Dominion East - Ohio, Sempra	Ohio, California
GT Instrument by GMI	Uses a semiconductor sensor for methane detection (PPM) and a catalytic bead sensor for the Lower Explosive Limit (LEL) (Source: GMI Website) The Gascope Combustible Gas Indicator is prepared for operation by turning the switch to the ON position, and setting the selector switch for high or low scale. A sample is drawn in by squeezing the aspirator bulb. The instrument uses two different types of filaments: a catalytic combustion filament for the low range, and a thermal-conductivity filament for the high range. Concentrations on the low range are measured by the hot-wire, Wheatstone bridge method. The filament is one arm of the bridge. When a gas sample is passed across this filament, combustibles are burned, raising the temperature of the filament. As a result, resistance is increased and the bridge becomes unbalanced. The imbalance is proportional to the concentration of the combustibles, and is indicated on the low range of the meter. For measuring in or above the explosive range, a thermal-conductivity filament is used. Combustibles in the sample cool this filament, causing the Wheatstone bridge to go out of balance. The imbalance, proportional to the gas concentration, is measured by the meter and read as percent-by-volume. The filament is field replaceable.	Overview - Designed for the gas industry, the GT Series are multi-application instruments, satisfying all the needs of service technicians within a single unit. With 7 modes of operation, the GT Series is the most versatile instrument available for working with gas. The GT Series is suitable for the following operations: Leak test, Confined space entry, Barhole testing, Carbon monoxide, Purge, Sniffer, Pressure leak tightness. (Source: GMI Website)	0-10,000 ppm in increments of 1 ppm 0-100% LEL in increments of 1% (Source: GMI Website)	<a href="http://www.gmiuk.com/product/et-series/">http://www.gmiuk.com/product/et-series/</a>	Must contact the vendor	The GT range of instruments combine quality, ruggedness and advanced GMI Technology in a user friendly, hand held gas detector. • PPM, LEL and Volume Methane flammable gas ranges for leak detection • Manual and automatic datalogging • Loud audible and high visual 'ticker' (Geiger) on ppm range • Integral flashlight • Alkaline or rechargeable battery options • Charging via simple power cable or docking station • Rugged polycarbonate case, sealed to IP54 Bump Test & Calibration Station • Simple user interface • Full bump test and calibration options • Bump test and calibration results storage • Robust construction. It is also light weight at 1.7 lbs. (Source: GMI Website)	Must come in contact with the gas to sniff it.	<a href="#">See the link at the left for the manufacturer's website and brochure</a>	Sempra	California
Combustible Gas Indicator - Gascope Model 60 by MSA	(Source: MSA)	The Model 60 is designed for use by gas utility companies in routine testing for methane-in-air concentrations in manholes, sewers, curb boxes and other street openings. The unit reads 0 to 5% by volume methane-in-air, and 0-100% by volume methane-in-air. (Source: MSA)	The unit reads 0 to 5% by volume methane in air and 1-100% by volume methane in air. (Source: MSA)	<a href="#">There is no direct link to this device. It does not appear on the website of MSA the manufacturer. Instead you must type "gascope model 60" into a search browser. One of the selections will be "media.msanet.com". Click on it.</a>	Per internet search - Approx \$3000 <a href="http://www.superiorvalueproducts.com/MSA-Gascope-Combustible-Gas-Indicator-Model-60-465475_p_1944.html">http://www.superiorvalueproducts.com/MSA-Gascope-Combustible-Gas-Indicator-Model-60-465475_p_1944.html</a>	<ul style="list-style-type: none"> <li>■ Effective measurement of combustible gases and vapors</li> <li>■ Excellent for pinpointing leaks</li> <li>■ 3 Models to meet differing detection needs</li> <li>■ Impact-resistant, waterproof case</li> <li>■ Equipped with neck and waist straps for hands-free operation</li> </ul>	Silanes, silicones, silicates and other compounds containing silicon in the tested atmosphere may seriously impair the response of this instrument. Some of these materials rapidly poison the catalytic combustion filament so that it will not function properly. When there is even a suspicion that such materials are in the atmosphere being tested, the instrument must be checked frequently (at least once every five uses). Calibration kits are available to conduct this test. Leaded gasoline vapors can also poison the catalytic combustion filament. To prevent this, an inhibitor filter (Part No. 47740) should be used to nullify their effect.		Sempra	California
Leakator 10 by Bacharach	This easy-to-use instrument detects acetone, acetylene, ammonia, benzene, butane, ethanol, ethylene-oxide, gasoline, hexane, hydrogen, industrial solvents, methane, naphtha, natural gas, paint thinners and propane. (Source: Bacharach Corp.)	Hand held light weight gas detector. This easy-to-use instrument detects acetone, acetylene, ammonia, benzene, butane, ethanol, ethylene-oxide, gasoline, hexane, hydrogen, industrial solvents, methane, naphtha, natural gas, paint thinners and propane. (Source: Bacharach Corp.)	20 ppm for Methane (Source: Bacharach Corp.)	<a href="http://www.bacharach-inc.com/leak-detection.htm">http://www.bacharach-inc.com/leak-detection.htm</a>	Must contact the vendor	10 bright red LED's and a speaker that provide visual and audible indications to the presence of gas • Three operation-status LED's that show power on, sensor operation and low battery • Simple thumb wheel on/off allowing for one-handed operation • Solid state plug-in sensor with typical five year life • 20 inch flexible probe for hard to reach areas • Operational status LED's in English and International systems • UL 913 Classified. Small and Light - Only 18 ounces - Detects many combustible gases, not just methane. Low Maintenance and relatively inexpensive. (Source: Bacharach Corp.)	Cannot distinguish between Methane and other combustible gases. (Source: Bacharach Corp.)	<a href="http://www.bacharach-inc.com/leakator-10.htm">http://www.bacharach-inc.com/leakator-10.htm</a>	Sempra	California

Name	Technology	Uses	Detection Sensitivity	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files	Utility Company	Location	
Portable Flame Ionization Detector	The operation of the FID is based on the detection of ions formed during combustion of organic compounds in a hydrogen flame. The generation of these ions is proportional to the concentration of organic species in the sample gas stream. Hydrocarbons generally have molar response factors that are equal to number of carbon atoms in their molecule, while oxygenates and other species that contain heteroatoms tend to have a lower response factor. Carbon monoxide and carbon dioxide are not detectable by FID. <b>There is now a replacement for FIDs. It is called DP-IR see line 10 of this spreadsheet.</b> (Source: Consumer's Energy Presentation to AGA - 2011 and Wikipedia)	Sensitive, economical, single purpose gas leak Flame Ionization Search Instrument. One instrument for walking, ATV and mobile surveys. Provides eight hours of continuous operation and can be refueled in one minute or less. Ideal for checking mains, services, congested areas, meter sets and risers. Weighs 4½ lbs. Meter, audible alarm and LED flame out indicator provide the readouts. (Source: Southern Cross Inc.) Walking Leak Survey or Mobile Surveys. See the brochure for all of the uses of this instrument: <a href="http://heathus.com/wp-content/uploads/detecto-pak-4.pdf">http://heathus.com/wp-content/uploads/detecto-pak-4.pdf</a> (Source: Consumer's Energy Presentation to AGA - 2011 and Heath)	In the search range, (50 ppm @ full scale), it is capable of detecting as low as one part per million (ppm) of hydrocarbons in air. A centering range, (5000 ppm @ full scale), is provided to assist in centering leaks. The meter indicates the presence of hydrocarbons. An alarm sounds at a preset point on the search range. (Source: Southern Cross Inc.)	Several manufacturers easily found on the internet. One of them is Heath: <a href="http://heathus.com/product_category/gas/flame-ionization-fid/">http://heathus.com/product_category/gas/flame-ionization-fid/</a> Another manufacturer is Southern Cross: <a href="http://southerncrossinc.com/products/flame-pack-400">http://southerncrossinc.com/products/flame-pack-400</a>	Must contact the vendor	Flame ionization detectors are used very widely in gas chromatography because of a number of advantages. Cost: Flame ionization detectors are relatively inexpensive to acquire and operate. Low maintenance requirements: Apart from cleaning or replacing the FID jet, these detectors require no maintenance. Rugged construction: FIDs are relatively resistant to misuse. Linearity and detection ranges: FIDs can measure organic substance concentration at very low and very high levels, having a linear response of 10%. Life is eight hours with fully-charged battery and two fuel cylinders filled to 1,750 psig. (Source: Wikipedia) They are rugged and light and can be hand carried, mounted on an ATV or other vehicle. (Source: Southern Cross Inc.)	1. Requires the use of High Pressure (1750 psi) Hydrogen / Nitrogen gas to fuel the flame. It can be dangerous if not used properly. 2. Must be able to come in contact with the gas to sniff it. 3. Requires maintenance and frequent calibration checks. 4. <b>Heath states that the Heath Detecto Pak Infrared (DP-IR) is the next generation of methane detection equipment and is the replacement for FIDs. DP-IR is next generation technology utilizing a simple light beam, eliminating the need for expensive gas cylinders and refill systems. See Line 10 of this spreadsheet.</b> (Source: Heath website)	<a href="http://southerncrossinc.com/technology-products/">http://southerncrossinc.com/technology-products/</a>	<a href="http://heathus.com/wp-content/uploads/detecto-pak-4.pdf">http://heathus.com/wp-content/uploads/detecto-pak-4.pdf</a>	Consumers Energy-Michigan, PG&E, Central Valley Storage, Gil Ranch Storage, Lodi Gas Storage, Dominion East-Ohio, Southern California Edison (SCE), Southwest Gas	Ohio, Michigan, California, Nevada, Arizona
Combustion Gas Indicator (CGI)	Semi-conductor Sensor Probe connected to instrument with electrical harness or Standard Probe and Handle assembly using instrument integral pump with flow fail sensor. The sample path is protected by hydrophobic filter and automatic pump switch off. (Source: Heath)	The First Responder gas detector provides gas detection for first call and emergency response technicians in the gas utilities. It can be used as a Combustible Gas Indicator with LEL and % Volume ranges for leak detection and general safety monitoring. Additionally, the First Responder has a Carbon Monoxide range for internal atmosphere monitoring where odor call response is required. There are currently three CGIs utilized at SCE Catalina: GMI Acclaim, Impact Pro, and the Sensit □ HNZ-2D. The GMI Acclaim is a portable combustible gas indicator that can detect the presence and concentration of combustible gases. The Impact Pro is a portable gas monitor designed to monitor the atmosphere continuously for hazardous levels of oxygen, combustible gas, carbon monoxide, and hydrogen sulfide. The Sensit is in both the PPM and %LEL range.	1 PPM (Source: Heath)	<a href="http://heathus.com/products/first-responder-gas-detector/">http://heathus.com/products/first-responder-gas-detector/</a>	Must contact the vendor	Portable, easy to use, easy to set up, fast, provides permanent repeatable measurements and records. Relatively inexpensive. (Source: Heath)	It cannot detect gas unless it is able to sniff it so it has to be close to the leak.		PG&E, Alpine, Central Valley Storage, Lodi Gas Storage, Southern California Edison (SCE)	California	
Gas Rover by Bascom-Turner	The Gas-Rover™ uses a catalytic combustion sensor to provide sensitivity, speed of response, and accuracy needed for leak surveys on foot or by vehicle. The Rover can be used to replace a conventional FID with a significant reduction in cost and a substantial increase in convenience. (Source: Bascom-Turner Website)	Use it to conduct gas leak surveys by foot or vehicle (Source: Bascom-Turner Website)	Measurements over the full range of gas from 1ppm to 100% gas. Survey mode provides a calibrated scale from 1ppm to 10,000 ppm. Barhole mode yields peak and sustained readings after a fixed time (Source: Bascom-Turner Website)	<a href="http://www.bascomturner.com/rover.php">http://www.bascomturner.com/rover.php</a>	Must contact the vendor. Supposedly cheaper than a Flame Ionization Detector (Source: Bascom-Turner Website)	<ul style="list-style-type: none"> <li>Measurements over the full range of gas from 1ppm to 100% gas</li> <li>Survey mode provides a calibrated scale from 1ppm to 10,000 ppm</li> <li>Barhole mode yields peak and sustained readings after a fixed time</li> <li>Optional sensors for CO and O2</li> <li>Intrinsically safe design for indoor and outdoor use</li> <li>Visual and audible alarms for all monitored gases</li> <li>Optional GPS capabilities &amp; Bluetooth functionality</li> <li>Optional 1 Gas Calibration</li> <li>Retrieve field and calibration data with DataLink4Access</li> <li>Use the Rover to become Method 21 Subpart W compliant</li> <li>Automatic calibration, stand-alone and/or in-network docking stations</li> <li>Automatic storage of mode and time-stamped data</li> <li>USB interface for data transfer and area network</li> <li>Two-speed pump automatically set for the job on hand</li> <li>Large, bright, backlit LCD display with short manual on-board</li> <li>Sturdy construction in an ergonomic 24 oz package</li> </ul> Supposedly, the Rover can be used to replace a conventional FID with a substantial increase in convenience. (Source: Bascom-Turner Website)			Southwest Gas	California, Arizona and Nevada	
Smart Ball	Free-swimming acoustic monitoring device. It can identify the sound of leaks. (Source: Technical Toolboxes Inc.)	Rolls through pipes 4" and above, propelled by the flow of the gas. Used for routine leak surveys, including pin-hole sized leaks, emergency leak location, minimizing product loss and cleanup costs, validation of alarms generated by CPM systems (with leak location), acceptance testing of new pipelines, product theft detection, leak location during hydrotests. (Source: Technical Toolboxes Inc.)	0.1 liter/min (Source: Technical Toolboxes Inc.)	<a href="http://www.ttoolbox.com/products/smartball/">http://www.ttoolbox.com/products/smartball/</a>	Must contact the vendor	Easy to deploy and tack throughout inspection, long battery life allows for long distances to be inspected in one deployment, can detect "pinhole" leaks as small as 0.016 GPM (0.06 LPM), which is typically several orders of magnitude more sensitive than some leak detection systems, maneuvers quickly and easily through a pipeline (the ball is smaller than the inside diameter of the pipe), light weight for easy shipping and tool preparation. (Source: Technical Toolboxes Inc.)	Cannot be used in pipes below 4" in diameter. (Source: Technical Toolboxes Inc.)		N/A	N/A	
Robots	<b>Design News - Robot Can Detect Gas Pipe Leaks</b> By Ann R. Thryft, July 18, 2014 In more than one US location gas pipes under city streets have exploded, causing damage and even death. Aging, failing underground pipes carrying natural gas can be notoriously difficult to troubleshoot. Now, a self-propelled robot developed by MIT researchers promises to detect leaks quickly and accurately. Researchers at MIT and King Fahd University of Petroleum and Minerals in Saudi Arabia say their prototype robotic system can detect very small leaks of 1 mm to 2 mm and at lower pressures. Existing leak detection methods tend to be slow and incapable of finding small leaks. They usually involve either leak detectors located inside pipes that use cameras for visual inspection, or acoustic sensors above ground that detect characteristic sound and vibration patterns. Other methods include hydrostatic or liquid natural gas testing and aerial patrols equipped with lasers. This system detects leaks by sensing a pressure gradient near a leak in the pipe using force-resistive sensors. The small robot has wheels to propel it through a gas pipe. A drum-shaped projection from the robot's body houses a membrane that forms a seal across the pipe's diameter. Liquid flows in the direction of a leak and pulls the membrane slightly toward it. This creates a distortion detected by the sensors, and their data is sent back using wireless communications. The system can detect leaks quickly and pinpoint their location. The robot can potentially go faster than 3 mph, a limit set by motor speed, not sensor speed.	Detects very small gas leaks	Detects very small leaks of 1mm to 2mm at low pressures. (Source: Design News - Robot Can Detect Gas Pipe Leaks By Ann R. Thryft, July 18, 2014)	<a href="http://www.designnews.com/author.asp?section_id=1392&amp;doc_id=274104">http://www.designnews.com/author.asp?section_id=1392&amp;doc_id=274104</a>	N/A - Not commercially available yet.	Fairly fast. It travels at least 3 MPH with the potential to go faster. Almost entirely automated.	It looks like the robot cannot adapt to different pipe sizes. In other words you would need a separate robot for each pipe size. Not commercially available yet.	<a href="http://spectrum.mit.edu/continuum/robot-patrols-gas-pipes-for-dangerous-leaks/">http://spectrum.mit.edu/continuum/robot-patrols-gas-pipes-for-dangerous-leaks/</a>	<a href="http://www.youtube.com/watch?v=Nq003mmmiURt=12">http://www.youtube.com/watch?v=Nq003mmmiURt=12</a>	N/A	N/A

Name	Technology	Uses	Detection Sensitivity	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files	Utility Company	Location
Tunable Laser Spectrometer	By measuring the absorption of light at specific wavelengths, the tool can measure concentrations of methane, carbon dioxide and water vapor and different isotopes of those gases.	It is used to find and pinpoint methane leaks	PG&E says it's 1,000 times more sensitive than the hand-held equipment it's been using to track down leaks. NASA says 1.3 parts per billion.	<a href="http://trc.nasa.gov/dspace/handle/2014/42732">http://trc.nasa.gov/dspace/handle/2014/42732</a>	Possibly as low as \$5000 per unit	Small, handheld and extremely sensitive. The laser and detector themselves are very small. The laser, the size of a quarter and the detector, the size of a penny. See the file in the Presentations and Useful Files column	It cannot survey widespread areas. - Not commercially available yet.	Excerpts from KQED-FM - PG&E Tests Tech Adapted From NASA's Mars Rover - By Molly Samuel, October 2 Pacific Gas and Electric is testing a new device for detecting methane leaks. The sensor is based on a tool that's mounted on NASA's Mars Curiosity rover. NASA designed PG&E's new gadget, too, which the utility says is 1,000 times more sensitive than the hand-held equipment it's been using to track down leaks. The sensor is a small, ultra-sensitive device, mounted on the end of a pole, so that it looks a little like a golf club, explains Hailey Wilson, a PG&E spokeswoman. Inspectors can walk around with it, and it will notify them of leaks in real-time. Methane is the main ingredient in natural gas. "It helps us localize the leaks quicker," Wilson says. "So it's not like it's picking up leaks that we wouldn't find eventually, but it enables us to find it much more quickly and fix it much more quickly." PG&E currently monitors for natural gas leaks by helicopter, boat, car and foot along its nearly 48,000 miles of pipelines. The utility has begun using another ultra-sensitive methane detector, which is mounted on cars. While the Picarro car can sweep neighborhoods for leaks, Wilson says, hand-held devices are vital for pinpointing the sources. "There's a safety component, it makes sure that our system is even safer," Wilson says. "But there's actually that green component as well, with making sure that we eliminate as much methane emissions — which is a greenhouse gas — as possible." On Mars, the Curiosity rover is using the tool, called the tunable laser spectrometer, to search for traces of methane in the atmosphere. There, though, the methane wouldn't signal a leak, but would instead, perhaps, be a sign of life. "Anytime we can go out and find an application that addresses real world problems — in this case one that relates very closely to global climate change and greenhouse gas concentrations — NASA is very supportive," says Andrew Aubrey of NASA's Jet Propulsion Lab in Pasadena. "So in this particular instance, it's a Mars technology that we are translating to the needs of the oil and gas industry." Right now, PG&E is testing a prototype of the sensor. The company is planning to deploy more of them in the field in 2015.	PG&E	California
Portable Spectrometer	By measuring the absorption of light at specific wavelengths, the tool can measure concentrations of methane, carbon dioxide and water vapor and different isotopes of those gases.	UC Davis is also using it to perform surveys of methane emissions from the air. The project is funded by PG&E and the Pipeline Research Council (PRCI):	Very sensitive but needs refinement to differentiate the signature of pipeline methane from naturally occurring methane.	<a href="http://www.sfgate.com/business/article/Methane-detector-tracks-pipeline-leaks-4071523.php">http://www.sfgate.com/business/article/Methane-detector-tracks-pipeline-leaks-4071523.php</a>	Fixed Wing Aircraft are much cheaper than helicopters using lasers. This equipment can be bought off-the-shelf for about \$50,000 and easily mounted on an airplane.	You can survey large areas from the air. More accurate than looking for dead vegetation, especially in the summer when weeds and grass are brown anyway.	Currently in the research stage. Currently working to differentiate natural gas from pipelines from natural sources of methane.		PG&E	California
Canines (Dogs)	Trained Dogs. A gas detection team consists of a handler and 2 gas detection dogs. The following is from the Maribo company website: "The teams are trained according to specifications established by Swedish authorities and Maribo. According to impartial experts, Swedish requirement specifications are among the most stringent in the world. The fact that Swedish authorities place significant demands on handlers and service dogs is primarily due to a low political acceptability for failure. High demands from authorities and the market drive development. Maribo develops detection functions in cooperation with customers who have cutting-edge skills in their fields. Examples of customers who have cutting-edge skills include Vattenfall, Orica Sweden, Eon Sverige, Euroco Bofors and Fortum Corporation. The training of teams from Maribo comprises expert technical content." (Source: Maribo website)	Find transmission and distribution line leaks	Performance is continuously monitored and results show that reliability is around 96%-97%. Chromatographs show that a gas detection dog detects values far below the PPB level. " (Source: Maribo website)	<a href="http://www.maribo.se/gas-detection.html">http://www.maribo.se/gas-detection.html</a>	Must contact the vendor	Maribo GDD-Teams have cutting-edge skills and experience; reliability for detection performance is 96%-97%. Search tags (i.e. all substances GDD identifies) are made up of exclusive substances (not freely occurring substances) and Maribo teams can detect gas leaks in gas pipelines located above or below ground. A gas detection dog from Maribo can identify gas leaks in environments contaminated by gas. GDD-Teams have technical expertise in gas pipelines and expertise in drawings and maps. Maribo gas detection dogs can serve in any environment where people and animals live, and they demonstrate great insensitivity to normally occurring heights, tunnels, traffic, people, animals and sounds. GDD-Teams can operate in the temperature range of -8°C to +32°C. At daytime temperatures above +32°C detection is performed during the cool part of the day. GDD-Teams can operate in hilly terrain and urban areas in wind with a force up to 25m/s; in open flat terrain in a constant wind with a force up to 17m/s*; and in open flat terrain in a gusty wind with a force up to 12m/s*. Maribo gas detection dogs can work in moderate rain or snowfall (they do not perform detection where there is ice formation in soil) and can work for ten consecutive hours while maintaining reliability in detection performance. The average control distance per day is 5,000m (when working with detection only) and for maintenance inspections Maribo gas detection dogs average 32 valves per working day (when working with valves only). Gas detection services provided by Maribo GDD-Teams can fix discrepancies in the distribution system. All reports are provided according to instructions from clients. * In open flat terrain there is some limitation when the wind is strong and/or gusty. (Source: Maribo company website)	The company is in Sweden	<a href="http://www.power-technology.com/contractors/safety/maribo/">http://www.power-technology.com/contractors/safety/maribo/</a>	Numerous European Companies use their services	Europe
Canines (Dogs)	Trained Dogs	Find transmission line leaks	See the line above. Tests have shown that they can detect gas in the parts per billion (ppb) range	<a href="http://detector-dogs-services.com/0/%20and%20gas%20services.html">http://detector-dogs-services.com/0/%20and%20gas%20services.html</a>	Must contact the vendor	This information is from the Detector Dogs International (DDI) webpage: "When you use dogs for leak detection, you only have to dig once. Dogs can be used during leak audits and can also be used in pipeline maintenance, especially on lines that are 30 or more years old. This part can be critical to any company because the dogs are fast and in a situation where you do not want to shut down a line, the dog can be used to locate a leak on an active line. Dogs are wonderful detection tools, suited for use in even the most environmentally sensitive areas. The weight of the dog does not destroy sensitive flora or grasslands, as a huge mechanical shovel would. The dogs do not have to be brought in by huge trucks to a location — they are themselves self-propelling. And to date, no hi-tech machine can match the sensitivity of a dog's nose — it's that powerful! Dogs can serve as a powerful general maintenance tool to locate leaks on active lines before the leak can spread into small rivers and creeks or on to farmers' fields. DDI employs specially trained dogs that are able to detect actual leaks to an accuracy of less than half a metre. Unlike mechanical devices, the leak detection success rate of healthy, properly trained DDI dogs is 100%." No need to drag leak detection equipment into mountainous or rugged terrain. More cost effective than leak detection equipment. (Source: Detector Dogs International (DDI))	Optimal pipeline pressure of 1000psi or more. Less pressure takes longer for the dog to find the leak. The company is in Alberta, Canada	<a href="http://www.ccpa.com/detector-dogs-sniffing-out-pipeline-leaks">http://www.ccpa.com/detector-dogs-sniffing-out-pipeline-leaks</a>	Numerous Canadian use their services	Canada
Canines (Dogs)	Trained Dogs - Locating leaks in oil and gas pipelines using highly trained leak detection dogs. Our dogs sniff out the specialized odorant that is injected into the oil or gas pipeline. The odorant then rises to the surface allowing the scent to be recognized and located by the man and dog teams. This method saves the oil and gas company time, manpower, equipment usage and money. We offer maintenance inspection packages on all existing pipeline. Our customers don't have to wait for a leak to occur but employ a standard inspection schedule of their pipeline, saving even more time and money. Our dog teams locate potential problems before they become a major risk. Monthly, Bi-Monthly, quarterly and six months maintenance inspection scheduling packages available. (Source: K9 Pipeline Leak Detectoin LLC website)	Find transmission and distribution line leaks	See the line above. Tests have shown that they can detect gas in the parts per billion (ppb) range	<a href="http://www.canineoilpipelineservices.com/index.html">http://www.canineoilpipelineservices.com/index.html</a>	Must contact the vendor	The company is K9 Pipeline Leak Detectoin LLC. According to their website, "Within the U.S. our handler and dog teams can be mobilized and on your job site within 72 hours after initial activation. Please call for Canadian mobilization time frame and other locations worldwide. Our Pipeline Leak Detector Dogs and handlers go through an extensive six week training course. Only dogs with extreme desire and stamina are selected as Pipeline Leak Detector Dogs. Our dogs can work in temp ranging from 32 degrees up to 95 degrees. A minimum of two Pipeline Leak Detector Dogs are used for each assignment up to four depending on circumstances." one dog can cover up to 5 miles per day in an open field and many miles of Neighborhood blocks if needed. Most jobs we use multiple dogs and trade them out as needed along with multiple handlers.	K9 Pipeline Leak Detection is in Florida	We offer the sale of pipeline leak detection dogs to agencies and individuals and teach the process to include the chemical to students. You can visit our training academy website at <a href="http://www.k9pta.com">www.k9pta.com</a>  If you should have any further questions feel free to contact me at <a href="mailto:pnichol@atlantic.net">pnichol@atlantic.net</a> or you can call me at 352 552-4855.  Thanks,  Paris Nicholson President K9 Pipeline Leak Detection K9 Pipeline Training Academy  Their website <a href="http://www.canineoilpipelineservices.com/services.html">http://www.canineoilpipelineservices.com/services.html</a>	Numerous	U.S. and Canada

Name	Technology	Uses	Detection Sensitivity	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files	Utility Company	Location
Aerial Leak Surveys Using Drones	Small remote control helicopters that can be fitted with cameras and a variety of sensors.	Drones are being tested now by SDG&E to inspect power lines and towers. In the future they may also be used to inspect gas lines and other infrastructure. One possibility is to fit the drones with miniature tunable laser spectrometers to detect gas (see the Leak Survey and Repair Methods tab on this spreadsheet).	N/A	<a href="http://3drobotics.com/">http://3drobotics.com/</a>	Each Drone costs \$750-\$1100, depending on the type of drone and options chosen	Inexpensive. In some cases, drones can get closer to infrastructure than humans or helicopters, especially in rugged areas.	The FAA has not yet approved the use of drones. SDG&E is the only utility approved to test them at the current time. Helicopter drone has 15-20 minute battery life. However, the fixed wing drones can stay in the air for 40 minutes. They cannot stay in the air as long as a standard helicopter or cover as much territory. It's best if drones stay within sight of someone.	<p>Inspections - Utility Gets FAA OK for Limited Operation - By Brad Graves, October 27 - Here in a utility yard near Interstate 805 in Serra Mesa, the two San Diego Gas &amp; Electric Co. workers are pushing forward the utility's experiment of using small unmanned aircraft to inspect its sprawling network of electrical and gas lines. SDG&amp;E, a unit of Sempra Energy (NYSE: SRE) is among many businesses preparing to put model-sized "whirlybirds" and fixed-wing aircraft to work, as a way of gaining new insights into their businesses and as a means of saving money. Whirlybird flights may one day replace inspections by manned helicopter. Putting a manned helicopter in the air is an expensive proposition, said Dallas Cormier, a project manager with the utility and the head of its unmanned system effort. Under federal law, businesses cannot yet use unmanned aircraft to do work in U.S. airspace. That may change by this time in 2015. For the present, the Federal Aviation Administration has made a few exceptions to its rule. One exception has been for certain movie studios working on closed sets. Another has been for SDG&amp;E, which is the first utility to get permission to test such systems and train flight crews. The permission is limited to five specific patches of real estate. Of all the utilities in all 50 states, how did SDG&amp;E get here first? The culture of safety had a lot to do with convincing the FAA, Cormier said. Cormier prefers to call the Little aircraft UASes, short for unmanned aircraft systems — or simply "birds." Today, Deering — a retired U.S. Navy pilot — has the control box. Ortiz holds the aircraft; he will keep an eye on it while it's airborne. "Coming on," Deering says, and the propellers start spinning. The machine buzzes like a swarm of insects. Soon it is flying at an altitude of 103 feet, beaming down images of a utility pole. "I'm going to go to the tower," Deering said, and the little aircraft darted south to a spindly metal structure. The unit is able to zip quickly from one spot to another in the 100-foot-diameter flying zone approved by the FAA. The utility flies the whirlybirds as if they were manned helicopters, following every rule and regulation, Cormier said. It has to file flight plans. Before showing off the capabilities of their quadcopter, Deering and Ortiz go through a pre-flight checklist. When it comes time to work on the aircraft, all maintenance tasks are recorded in a logbook. SDG&amp;E plans to test its flying</p>	SDG&E - SDG&E is the first utility in th country to get permission to test the use of drones and train the crews to operate them.	California
Patrols Using Helicopters, Fixed Wing Aircraft, Cars, Boats, On Foot or any combination of these.	All of the methods on the left, with or without cameras or gas detection devices.	<p>Landslides or threatened slides. Erosion by streams, wave action, rain, etc.. Land subsidence that could affect the pipeline. Construction or maintenance work being done by others along the pipeline. Encroachments into the right-of-way by buildings, structures or the construction of levees, roads, wells, etc. for which no prior permission has been granted by the company. Evidence of gas leakage, by checking vents at RR crossings or as indicated by vegetation (See Procedure 5.02, Leakage Surveys), bubbles in surface water, odor, etc.. Needed repairs to company owned facilities, including fences, pipeline markers, exposed crossings, etc. Needed repairs to highway structures and other non-company owned facilities where public safety is a factor. Presence of survey parties or other indications of possible future work that might jeopardize the pipeline or affect a change in its class location. Any other factors affecting the operation or safety of the pipeline or other company facilities such as slope erosion, blocked culverts, casing vents, and access road washouts. Evidence of atmospheric corrosion that would indicate the need for repair and/or re-coating. Access roads used by others occasionally, or in areas viewed by the general public that may not be in a passable condition as established in accordance with existing agreements. Changes in population density. Any activity that could create an unsightly condition in aesthetically sensitive areas.</p>	Usually patrols are visual however, they are becoming more sophisticated using gas detection technology.		Varies by vendor providing the service.	Covers a lot of mileage in a relatively short amount of time.	Imprecise way to search for gas leaks. Basically the spotter is looking for dead vegetation		PG&E	California
Hyperspectral Imaging Cameras (Rebellion Photonics)	Hyperspectral imaging collects and processes information from across the electromagnetic spectrum. The goal of hyperspectral imaging is to obtain the spectrum for each pixel in the image of a scene, with the purpose of finding objects, identifying materials, or detecting processes. Much as the human eye sees visible light in three bands (red, green, and blue), spectral imaging divides the spectrum into many more bands. This technique of dividing images into bands can be extended beyond the visible. In hyperspectral imaging, the recorded spectra have fine wavelength resolution and cover a wide range of wavelengths. (Source: Wikipedia and the references mentioned therein)	Detecting Methane Leaks	1% methane leaks at 160 ft. (Source: Rebellion Photonics)	<a href="http://rebellionphotonics.com/">http://rebellionphotonics.com/</a>	\$2-3 Million for a mid-sized refinery	You can see leaks on live video. Color coding identifies the severity of the leak. Rebellion Photonics offers a Gas Cloud Imaging video camera that monitors, quantifies, and displays, using a false-colored image, explosive/harmful gas leaks with real-time (~30 fps) video and hardware-based zoom. The camera can be used as an alarm, with 0.5 second response time, to notify of potentially dangerous leaks and aid in safety management. With breakthrough optics technology invented at Rice University, Rebellion Photonics can offer Gas Cloud Imaging video cameras which provide several new possibilities in refinery/rig safety: Detect more explosive, harmful leaks earlier, monitor large sections of a facility in real-time, night and day, visualize gas clouds with powerful false-colored video, zoom in on leaks to better understand size and dispersal, repair leaks more accurately due to portability, save video for future analysis and safety management. Automated calibration with annual maintenance. Unaffected by the wind or temperature, fully automatic 24/7. (Source: Rebellion Photonics webpage)	Not sure how portable it is. Wikipedia says it may require a lot of data storage capability. This is a highly pixelated digital video at 30 fps. Will require more investigation to determine if these disadvantages are accurate		N/A	N/A
Smart Pipeline Network - Pipe & Repair Sensor System	Odysian Technology believes that the correct approach to eradicating or significantly reducing pipeline leaks is a smart pipeline system that has a collection of diverse (and evolving) technologies all integrated within a distributed, yet common communication and control platform. The technology developed in these PHMSA SBIR programs take advantage of recent technology advances and shifts in affordability of technology to develop and demonstrate what Odysian believes will be our future national Smart Pipeline Network. Such technology advances include the advent of nano-scale and thin and thick film materials in conjunction with micro machining techniques that allow for the development of very small sensors and multifunctional systems having intrinsically embedded sensing functionality. These small devices and materials are being used to develop highly engineered smart systems that are capable of sensing their environment and often responding to such stimulus. Odysian Technology has developed smart pipe and smart seal technology, originally targeted for use on airborne high-energy chemical laser systems. This DOT PHMSA SBIR program further developed and adapted this technology for use on pipelines to allow for the pinpoint location of leaks and in some cases emerging leaks (detecting an imminent leak before leakage occurs). The shift in affordability and proliferation of wireless and wired communication networks makes more feasible a Smart Pipeline Network that provides real-time operational status of pipeline transmission, distribution, and remote facility systems. Communication and signal conditioning circuitry was developed that is integrated within the system to provide a sensor network capable of pinpointing the location of progressing leaks through fittings, joints, valves, pipe, pipe repairs, etc. For more information see the Final Report found via the link to the right. (Source: Odysian Technology)	Detect leaks in gas transmission lines. In this program, smart pipes and smart composite repair having integrated leak detection micro-sensors will be further developed and adapted for pipeline use. Concepts and designs will be developed for a networked sensing system capable of sensing the pinpoint location of a leak or impending leak, as well as monitoring structural health. In Phase I, the scope will include the development of a Pipe and Repair Sensor System for use with petroleum-based liquids, with Phase II expanding the scope to include development of a system for use with natural gas. For more information see the Final Report found via the link to the right. (Source: Odysian Technology)	Depends on the sensors used. Still in R&D Phase	<a href="http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=444&amp;c=1&amp;s=D92F98698A8F48E794167A2DE11068D2">http://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=444&amp;c=1&amp;s=D92F98698A8F48E794167A2DE11068D2</a>	In the R&D Phase - Preliminary estimate in the report is approx. \$9000 per sensor.	Using a system of sensors along the pipe to create a "smart pipe", the hope is that leaks will be detected sooner. It is very difficult to detect a leak from the control room.	In the R&D Phase - Not clear from the report		N/A	N/A
Gas Insertion Sensor System	In 2013 JD7 commercially launched its live gas insertion sensor system. This technology incorporates not only high resolution CCTV camera sensors but also a highly sensitive hydrophone and high powered sonde system. The hydrophone is used for precise leak detection and pinpointing purposes. The hydrophone and software is sensitive enough to detect the smallest of leaks within low pressure gas distribution systems. Full leakage acoustic signatures can be displayed graphically or using the conventional audio output as headphones and HD CCTV live images allow the operator to validate the full survey. The system includes a pressurised launch and feed system which allows safe and consistent feeding of the system during live insertion work. (Source: JD7 Inc.)	Determine the condition of low pressure distribution piping and locate leaks in low pressure gas distribution systems. (Source: JD7 Inc.)	The JD7 website just says "The hydrophone and software is sensitive enough to detect the smallest of leaks within low pressure gas distribution systems."	<a href="http://jd7.co.uk/products/gas-insertion-system.php">http://jd7.co.uk/products/gas-insertion-system.php</a>	Contact JD7. All products are available as a service, lease or sale.	The distribution system can be inspected while in service. The hydrophone is used for precise leak detection and pinpointing purposes. Full leakage acoustic signatures can be displayed graphically or using the conventional audio output as headphones and HD CCTV live images allow the operator to validate the full survey. The system includes a pressurised launch and feed system which allows safe and consistent feeding of the system during live insertion work. (Source: JD7 Inc.)	The company is in the UK.	<a href="http://digital.turnpage.com/4063217_cidee=Y2hhcmxlcYyWVdlZUBicHVLmNhlmdvdjg3dG%3d&amp;urlid=100threat/7_cidee=Y2hhcmxlcYyWVdlZUBicHVLmNhlmdvdjg%3d%3d&amp;urlid=7">http://digital.turnpage.com/4063217_cidee=Y2hhcmxlcYyWVdlZUBicHVLmNhlmdvdjg3dG%3d&amp;urlid=100threat/7_cidee=Y2hhcmxlcYyWVdlZUBicHVLmNhlmdvdjg%3d%3d&amp;urlid=7</a>	Several utilities in the UK	United Kingdom

# Appendix A - Natural Gas Leakage Abatement Best Practices

## Gas Leak Prevention Technology

Name	Technology	Uses	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files		Utility Company	State
Starline 2000 Cured In-Place Pipe Liner	Fabric Liner blown into a line, then glued to the pipe wall with epoxy coating. In the US, Nysearch and Con Ed (NY) have been testing it. Recently, a line that was coated 10 years ago was examined. <a href="http://www.starlinett.com/products/star_2000_2.html">http://www.starlinett.com/products/star_2000_2.html</a> <a href="http://www.nysearch.org/news-info_110514-1.php">http://www.nysearch.org/news-info_110514-1.php</a> (Source: Starline Website and NYsearch website)	In Europe it has been used to rehabilitate 250 miles of natural gas distribution mains ranging from 4" to 24". It is good for gas pressures up to 90 psi. Can be used in cast iron, steel, asbestos and PVC lines. <a href="http://www.starlinett.com/products/star_2000_2.html">http://www.starlinett.com/products/star_2000_2.html</a> (Source: Starline Website and NYsearch website)	<a href="http://www.starlinett.com/products/star2000.html">http://www.starlinett.com/products/star2000.html</a>	Contact the Vendor	Maintains gas-tightness even if the pipe breaks, misalignment of 7°, uniform bonding, i. e. no gas migration, new service tees can be installed using the utility's standard procedure, no significant reduction in pipe capacity. Cold-hardening system: The lines are cured overnight so that the pipeline can be put into operation again within 1½ working days. Warm-hardening system: Only a few hours are required for warm-hardening so that the customer can be resupplied with gas within 12 - 16 hours. Can be used to rehabilitate lines with partially deteriorated gas pipes, e. g. holes or gaps up to 4". (Source: Starline Website and NYsearch website)	Gas line is out of service for 12-16 hours	<a href="http://www.starlinett.com/products/star_2000_2.html">http://www.starlinett.com/products/star_2000_2.html</a>	<a href="http://www.nysearch.org/news-info_080514-2.php">http://www.nysearch.org/news-info_080514-2.php</a>	Con Ed, Public Service Electric and Gas and an unnamed European Utility	New Jersey, New York, Europe
Starline 200 Cured In-Place Pipe (CIPP) Liner	Fabric Liner blown into a line, then glued to the pipe wall with epoxy coating. In the US, Nysearch and Con Ed (NY) have been testing it. Recently, a line that was coated 10 years ago was examined. <a href="http://www.starlinett.com/products/star_200_2.html">http://www.starlinett.com/products/star_200_2.html</a> <a href="http://www.nysearch.org/news-info_110514-1.php">http://www.nysearch.org/news-info_110514-1.php</a> (Source: Starline Website and NYsearch website)	Used to line natural gas service lines ranging from 1" to 2-1/2". It is good for gas pressures up to 60 psi. Can be used in cast iron, steel and PVC lines. <a href="http://www.starlinett.com/products/star_200_2.html">http://www.starlinett.com/products/star_200_2.html</a> (Source: Starline Website and NYsearch website)	<a href="http://www.starlinett.com/products/star200.html">http://www.starlinett.com/products/star200.html</a>	Contact the Vendor	The pipe doesn't have to be replaced. Depending on the size of the rehabilitation crew, three to four services can be lined per day if the warm-curing method is used. Thus, customers are promptly reconnected to their gas supply. The starline®200 technology is a cost-effective, fast, and safe rehabilitation process for gas services. starline®200 lines the pipeline uniformly and wrinkle-free, even in 90° bends, with the rehabilitated line having at least the same life as a new HD PE service. A special-purpose self-contained installation truck has been developed in the United States to facilitate the cost-effective performance of the technology. Can be used to rehabilitate lines with heavy corrosion possible, e. g. holes or gaps up to 1". (Source: Starline Website and NYsearch website)	Unknown	<a href="http://www.starlinett.com/products/star_200_2.html">http://www.starlinett.com/products/star_200_2.html</a>	<a href="http://www.nysearch.org/news-info_080514-2.php">http://www.nysearch.org/news-info_080514-2.php</a>	Con Ed, Public Service Electric and Gas and an unnamed European Utility	New Jersey, New York, Europe
Nu Line by Nu Flow	The Nu Flow epoxy lining solution includes removing existing corrosion in the pipes and applying an epoxy coating without the need to dig or cut access points to underground, under-foundation or in-wall pipes. Unlike alternative epoxy barrier solutions, Nu Flow's epoxy and application process is effective in pipes from 1/2" up to 10" in diameter. The unique characteristics of the Nu Flow epoxy make it feasible to line longer lengths of pipe through elbows, tees and unique system constructs. The epoxy coating process restores flow and prevents corrosion which would otherwise lead to pinhole leaks. Prevents future leaks in hard to access areas such as under foundations or within walls and ceilings. Once completed, the Nu Flow solution ensures continued performance and long-term durability of the pipe system. Nu Flow restores gas systems using patented epoxy coatings. (Source: Nu Flow Corp)	Applicable for use in host pipes consisting of metal, iron, steel, plastic, concrete and fiberglass in pipe diameters ranging from 1/2" to 10", with larger custom sizes available. (Source: Nu Flow Corp)	<a href="http://www.nuflowtech.com/Products/EPOXYLINING.aspx">http://www.nuflowtech.com/Products/EPOXYLINING.aspx</a>	Contact the Vendor	The pipe doesn't have to be replaced. Existing interior corrosion is removed and new corrosion is prevented by the epoxy barrier. Can be used in pipes from 1/2" to 10" in diameter. The manufacturer says the epoxy withstands whatever pressure the host pipe can withstand.(Source: Nu Flow Corp)	Takes time to cure. Unknown how long that is.	<a href="http://www.nuflowtech.com/Products/EPOXYLINING/ExecutedAirLining/Applications/Gas.aspx">http://www.nuflowtech.com/Products/EPOXYLINING/ExecutedAirLining/Applications/Gas.aspx</a>	<a href="http://americanleakdetec4.eachlocal.net/epoxy-pipe-lining.php">http://americanleakdetec4.eachlocal.net/epoxy-pipe-lining.php</a>	N/A	N/A
No Dig Anode Installation	Anode installation on steel mains and services typically required utility companies to acquire a street opening permit and proceed to close off and excavate a large section of the street or sidewalk with heavy construction equipment. ULC Robotics was approached by a large gas utility in the Northeast US to see if it would be possible to install anodes by drilling through existing valve boxes or test stations. It was determined to be possible and is in commercial use. (Source: ULC Robotics)	Installing anodes on steel gas piping	<a href="http://www.ulcrobotics.com/portfolio/no-dig-anode-installation/">http://www.ulcrobotics.com/portfolio/no-dig-anode-installation/</a>	Contact the Vendor	The commercialized process has been performed several thousand times and has successfully reduced the cost of protecting steel mains and services by eliminating the need for permit acquisition and heavy construction equipment. In addition, the improved process reduces the time it takes to install anodes. (Source: ULC Robotics)				N/A	Somewhere in the Northeast U.S.

Name	Technology	Uses	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files		Utility Company	State
PipeGuard Proactive Damage Prevention System --- Senstar calls the product FiberPatrol-PR	A research partnership between PHMSA/DOT, NGA/NYSEARCH and Magal/Senstar to develop and test an acoustic warning system to proactively report third party activity near pipelines. NYSEARCH completed several successful tests with alpha prototypes and is now completing with PHMSA further advances to the product through development and testing the of beta prototypes.	Proactively report third party activity near pipelines. Also used as a security system to protect utility piping and infrastructure from intrusion.	<a href="http://senstar.com/products/fiberpatrol-pr-formerly-fiberlr-for-pipelines/">http://senstar.com/products/fiberpatrol-pr-formerly-fiberlr-for-pipelines/</a>	Contact the Vendor	FiberPatrol-PR is ideal for protecting pipelines and other in-ground infrastructure from Third-Party Interference (TPI). A single sensor can provide protection for up to 50 km (30 mi.) of sensor cable buried along the pipeline. FiberLR detects manual or machine digging, whether from intruders intent on damaging or tapping the pipeline or those accidentally digging near the pipeline's location. By providing an early warning and the precise location of an incident, the sensors helps responders prevent costly damage.FiberPatrol-PR accurately locates intrusions even when there are multiple simultaneous intrusions or in the presence of non-localized environmental noise that would overwhelm the location capability of other long-range fiber-optic sensors. FiberPatrol-PR's resilient design allows detection to continue right up to the point of a cut in the sensor cable. When installed in a redundant configuration, FiberPatrol-PR protects the full perimeter even after a cable cut. ( Source: Senstar)		<a href="http://primis.phmsa.dot.gov/rd/mtg_071812.htm">http://primis.phmsa.dot.gov/rd/mtg_071812.htm</a>	<a href="http://primis.phmsa.dot.gov/matrix/PriHome.rdm?pri=364">http://primis.phmsa.dot.gov/matrix/PriHome.rdm?pri=364</a>	N/A Contact the Vendor	N/A Contact the Vendor
Guided Wave Ultrasonics	Four separate research projects addressing GWUT with NYSEARCH and Southwest Research Institute led to commercial improvements with multiple service providers. As a result software and hardware support longer inspection distances and better characterization of defects. This technology is widely applied to inspect cased crossings nationwide. Use of magnetostrictive sensor guided-wave technology was also benchmarked.	Inspect and assess pipe walls and coating on buried pipes.	<a href="http://primis.phmsa.dot.gov/matrix/PriQuery.rdm?text1=guided+wave&amp;btn=Modern+Searc h">http://primis.phmsa.dot.gov/matrix/PriQuery.rdm?text1=guided+wave&amp;btn=Modern+Searc h</a>	Open each research project and refer to the commercial partners listed.	Inspect piping and coating in place without excavating. Inspect non-piggable pipes.				N/A Contact the vendors.	N/A Contact the vendors.
Micro-Magnetic Cased Pipeline Inspection Robot	New federal pipeline integrity rules require utility companies to evaluate thousands of gas mains buried beneath highways, railroad tracks and airport runways – each and every one cased inside a larger pipe. ULC Robotics imagined, designed and built a solution. The Micro-Magnetic Cased Pipe Inspection Robots defy gravity by magnetically attaching to the metallic casing pipe enabling them to crawl hundreds of feet into tight annular spaces. Front and rear mounted video cameras provide real-time, full motion video of the outer surface of the gas main. Pitch and roll sensors allow for remote navigation and provide the precise location of defects and anomalies. Includes laser measurement of defects. Temperature and humidity sensors continually monitor the environment inside the casing. An ultrasonic thickness sensor can be deployed to take spot wall thickness measurements. Using two forward projecting lasers, a video based measurement system may be used to take measurements of defects or objects within the casing annulus. (Source: ULC Robotics Website)	Provides video and sensor data for critical analysis of gas mains buried within cased pipe in high consequence areas. Determine the integrity of pipeline coating including delamination, holes and other defects. Determine the Integrity, composition and spacing of pipeline insulators. Measure the pipeline wall thickness. Measure atmospheric conditions (temperature, humidity) in the annular space. Determine the quantity and location of debris and water in the annular space. Determine the location of electrical shorts. (Source: ULC Robotics Website)	These tiny robots are manufactured by ULC Robotics and Honeybee Robotics. Their websites are; <a href="http://www.ulcrobotics.com/portfolio/micro-magnetic-cased-pipeline-inspection-robot/">http://www.ulcrobotics.com/portfolio/micro-magnetic-cased-pipeline-inspection-robot/</a> and <a href="http://www.honeybeerobotics.com/portfolio/pipe-inspection-robot/">http://www.honeybeerobotics.com/portfolio/pipe-inspection-robot/</a>	Contact the Vendors	The tiny robots can inspect pipes, casings and areas that were formerly inaccessible. They are magnetic and can therefore inspect the entire circumference of the pipe.		<a href="http://www.ulcrobotics.com/products/cased-pipeline-inspection-crawler/">http://www.ulcrobotics.com/products/cased-pipeline-inspection-crawler/</a>	<a href="http://www.nysearch.org/news-info_111914.php">http://www.nysearch.org/news-info_111914.php</a>	PG&E and National Grid	California and New England

Name	Technology	Uses	Link to Manufacturer or Research	Cost	Advantages	Disadvantages	Presentations and Useful Files		Utility Company	State
Variable Geometry Crawler – ULC Robotics, Inc.	Closed Circuit Television (CCTV) inspection of live gas mains	Assessment and Evaluation of Pressurized PE, Steel and Cast Iron Gas Pipelines, Inspection of Pipelines to Locate Water Infiltration, Location of Pipeline Damage and Features; Joints, Taps, Branches, Service Lines, Stub Services, Valve Inspection for Proper Orientation, Setting and Type, Pre- and Post-Pipeline Rehabilitation Surveys, Locate Water Blockages in Live Gas Mains. Can inspect pipes ranging from 2" to 48" (Source: ULC Robotics Website)	<a href="http://www.ulcrobotics.com/energy-services/cctv-camera-inspections-of-live-gas-mains/">http://www.ulcrobotics.com/energy-services/cctv-camera-inspections-of-live-gas-mains/</a>	Contact Vendor	<p>Live Gas Main Inspection Service Overview - Our live gas pipeline inspection services provides utility companies and pipeline operators with the comprehensive visual data need to assess pipelines for damage, signs of corrosion and take note of pipeline features that may not be recorded on utility maps. Information collected from our live gas main inspection services helps gas utilities prioritize maintenance activities by identifying the sections of main that may require more immediate attention.</p> <p>Reduced Excavation, Permit and Street Restoration Costs: Our camera inspection equipment enters your live gas mains through compact pits or low-cost keyholes and can inspect hundreds of feet of pipeline from just one access point.</p> <p>No Need to Shut Down Service: We remove the need to shut off service to customers, saving you the hassle and the cost of turn-ons and reights. Our service is also trenchless, which translates into less engineering and permit costs.</p> <p>Advanced Inspection Equipment: Our crews utilize our patented PRX250 live gas main inspection camera system and our live gas main crawler systems to deliver a thorough visual inspection of your live mains.</p> <p>Minimal excavation, the line can be inspected live gas mains up to 100 psi. Long tether - can inspect up to 500 feet of pipe through one opening. Can be used for Cast Iron, Steel, or PE piping. (Source: ULC Robotics Website)</p>		<a href="http://www.nysearch.org/commercial_products.php">http://www.nysearch.org/commercial_products.php</a>	N/A Contact Vendor	N/A Contact Vendor	
3-D Toolbox	Digital camera capable of photographing and providing detailed measurements of dents, corrosion or other damage on the outside of pipes. It was originally developed for the dental industry. (Source - 3-D Toolbox)	Photographic analysis of exterior pipeline anomalies	<a href="http://www.ttoolbox.com/products/3dtoolbox/whats_new.cfm">http://www.ttoolbox.com/products/3dtoolbox/whats_new.cfm</a>	Contact the Vendor	Portable, easy to use, easy to set up, fast, provides permanent repeatable measurements and records.(Source - 3-D Toolbox)		<a href="http://www.pgecurrents.com/2014/05/20/video-pge-using-new-tool-to-check-outside-of-pipeline-for-dents-corrosion/?utm_source=newsletter&amp;utm_medium=email&amp;utm_content=052214&amp;utm_campaign=pgecurrents">http://www.pgecurrents.com/2014/05/20/video-pge-using-new-tool-to-check-outside-of-pipeline-for-dents-corrosion/?utm_source=newsletter&amp;utm_medium=email&amp;utm_content=052214&amp;utm_campaign=pgecurrents</a>	PG&E	California	
Explorer (Robot)	According to Pipetel's website - The Explorer's magnetic flux leakage (MFL) capabilities inspect for metal loss while caliper sensors provide data on dent and mechanical damage. It also uses laser deformation sensor to detect and measure out of round defects and dents. The robot was developed by NYSearch, a subsidiary of the NorthEast Gas Association. A company called Pipetel provides inspection services which use the device. They actually perform the inspections and provide reports to the utilities describing their findings. (Source: Pipetel website) Also see: <a href="http://www.pipetelone.com/demo.html">http://www.pipetelone.com/demo.html</a>	This is a robot that can inspect previously unpiggable pipes due to its flexible design. It can adapt to a range of pipe sizes. For example the same robot can inspect pipes ranging from 20 to 26 inches in diameter. In all there are robots which can inspect pipes from 6" to 36" in diameter. (Source: Pipetel website)	<a href="http://www.pipetelone.com/index.html">http://www.pipetelone.com/index.html</a>	Contact the Vendor	Can inspect pipes which were previously un-piggable due to diameter changes, tight turns and geometry. Self propelled. Battery can be charged while the robot is inside the pipe. No need to remove it. One robot can inspect a range of pipes. Can detect metal loss, dents, mechanical damage, out of round. Also takes videos from the front and rear. Operates while the pipeline is in service. Wireless communication therefore no tethers necessary. According to Pipetel's website - Pipetel's inspection service is the ideal inspection tool for natural gas pipelines with: limited or no flow, short radius or mitered bends, valves, back-to-back bends, vertical segments, and pipelines without pre-built launch capabilities. Pipetel also inspects cased pipelines, and pipelines located at difficult to access locations such as underneath urban infrastructure. (Source: Pipetel website)	Cannot be used in pipes below 6" in diameter	<a href="http://www.nysearch.org/news-info.php">http://www.nysearch.org/news-info.php</a>	PG&E, Con Edison, Questar Gas,	New York, California, Utah, Idaho, Wyoming	
PHMSA R&D Projects	Various	Various	<a href="http://primis.phmsa.dot.gov/matrix/">http://primis.phmsa.dot.gov/matrix/</a>	Contact the Commercial Partners listed with each R&D Project.				Various		

# Appendix A - Natural Gas Leakage Abatement Best Practices

## Record Management Technology

Name	Technology	Uses	Cost	Link to Manufacturer	Advantages	Disadvantages	Company	State
Leak Survey Handheld Device	Programmable pocket PC of which there are many brands. Internal software can be custom written for the specific utility. (Source: Internet Search)	Used by gas leak surveyors to find gas services, record gas leak survey data and material condition, to conduct accurate, thorough and timely gas surveys, record appointments, plan gas leak survey path, track statistics, and be aware of on-the-job dangers.	Approx \$100-\$400 (Source: Internet Search)	Many types and manufacturers	Creates an accurate record of a leak survey. Eliminates illegible hand written records. Can be uploaded to database and used to create work orders. Helps to prevent mistakes and missed surveys	Records can accidentally be erased or the pocket PC may crash, wiping out records.	Consumers Energy	Michigan
Intermec CN3 - Discontinued - Replaced by Intermec (Honeywell) CN 70 or CN70e	Programmable pocket PC of which there are many brands. Internal software can be custom written for the specific utility. (Source: Internet Search)	Used by gas leak surveyors to find gas services, customer info, service info, record gas leak survey data and material condition, to conduct accurate, thorough and timely gas surveys, record appointments, plan gas leak survey path, track statistics, critical maintenance, hazardous conditions and on-the-job dangers. If a leak is found, the grade of the leak is entered and also the location of the crayon mark where the leak is. Takes 5-10 minutes to upload or download data. Leaks and identified conditions are tracked to completion. (Source WE Energy presentation to AGA in 2011).	Approx. \$1500-\$3500 depending on model chosen (Source: Internet Search)	<a href="http://www.intermec.com/products/cmptrcn70a/index.aspx">http://www.intermec.com/products/cmptrcn70a/index.aspx</a>	Speeds the leak survey process by automating some of the human preparation and recordkeeping, improves the safety of the leak surveyors by warning them of dangers and reduces errors by downloading or uploading data rather than using human transcription. Also see the link on the left	Possible to lose large amounts of data if the hand-held pc is damaged.	WE Energy	Wisconsin

Name	Technology	Uses	Cost	Link to Manufacturer	Advantages	Disadvantages	Company	State
Gas Survey and Maintenance Website	Web-based	<p>Create, modify, view, and print survey route information for service surveys and valve inspections. View and print Street Opening / Main Leak Survey maps. All details of leak inspection shown.</p> <p>Maintenance repair order is linked to work management system to monitor repair order status. Select services and file is sent to billing system which prints and mails letters. Provides a summary of compliance dates.</p> <p>List is sorted by the closest compliance date for each office. For maintenance items that do not have a work order created.</p> <p>Use the drop-down menus to search for maintenance to process. Quick data extracts for specific needs.</p> <p>(Source WE Energy presentation to AGA in 2011).</p>			<p>Eliminates the use of paper forms. Automated routing and sequencing of surveys. Provides relevant attribute and survey information to field technician. Eliminates manual data entry for inspections. Provides real-time inspection status to area managers and supervisors.</p> <p>Tracks leaks and maintenance to completion.</p> <p>Shares leak survey attempts and contacts with Customer Call Centers</p> <p>Automated processing with links to attribute systems.</p> <p>If service is retired, outstanding surveys and maintenance are completed. Automatically completes ABI and inside GSS if scheduled in same year to minimize customer disturbances.</p> <p>(Source WE Energy presentation to AGA in 2011).</p>	Hacking and server crashing. Must have a backup server and files.	WE Energy	Wisconsin
Maximo	IBM Maximo Asset Management is an enterprise asset management (EAM) software solution product produced by IBM. It is a solution which is used to operate, maintain and dispose of enterprise assets. (Source: Wikipedia)	Maximo has a work management module that can be used to generate and track work orders. It is also useful as a repository for equipment work history. Regarding gas leaks it is used to generate work orders for field personnel to evaluate and/or fix gas leaks and track the repairs. The software can also automatically generate new work orders where work is on scheduled intervals.	\$1000 - \$5000 per year depending on options chosen. See the link to the website in the column to the right.	<a href="http://www-03.ibm.com/software/products/en/maximoassetmanagement/">http://www-03.ibm.com/software/products/en/maximoassetmanagement/</a>	The data in Maximo can be used to perform analysis of crew work performance, create a work history for gas system components and track asset performance. Maximo can be programmed to automatically generate work orders on scheduled intervals. It can also be used to track assets and inventory	Hacking and server crashing. Must have a backup server and files.	Duke Energy	North Carolina, South Carolina, Ohio, Indiana, Kentucky

