Lessons Learned
from Natural Gas STAR Partners

Directed Inspection and Maintenance at Compressor Stations

Executive Summary

The U.S. natural gas transmission network contains more than 279,000 pipeline miles. Along this network, compressor stations are one of the largest sources of fugitive emissions, producing an estimated 50.7 billion cubic feet (Bcf) of methane emissions annually from leaking compressors and other equipment components such as valves, flanges, connections, and open-ended lines. Data collected from Natural Gas STAR partners demonstrates that 95 percent of these methane emissions are from 20 percent of the leaky components at compressor stations.

Implementing a directed inspection and maintenance (DI&M) program is a proven, cost-effective way to detect, measure, prioritize, and repair equipment leaks to reduce methane emissions. A DI&M program begins with a baseline survey to identify and quantify leaks. Repairs that are cost-effective to fix are then made to the leaking components. Subsequent surveys are based on data from previous surveys, allowing operators to concentrate on the components that are most likely to leak and are profitable to repair. Baseline surveys of Natural Gas STAR partners' transmission compressor stations found that the majority of fugitive methane emissions are from a relatively small number of leaking components.

Natural Gas STAR transmission partners have reported significant savings and methane emissions reductions by implementing DI&M. One 1999 study that looked at 13 compressor stations demonstrated that the average value of gas that could be saved by instituting a DI&M program at a compressor station is $88,239 per year, at an average cost of $26,248 per station.

Introduction

Transmission compressor stations boost pressure at various points along natural gas transmission pipelines to overcome the pressure losses that occur along a long distance pipeline. The more than 279,000 miles of natural gas transmission pipeline are supported by approximately 1,790 compressor stations. Most compressor stations are equipped with either gas-fired reciprocating compressors or centrifugal compressors (turbines). These compressors and associated components, such as pipelines and valves, are subjected to substantial mechanical and thermal stresses, and as a result are prone to leaks. Additionally, compressor station operations place significant pressure, thermal, and mechanical stresses on blowdown valves. These stresses wear down valve components (e.g., plugs, seals, seats) making them significant methane emissions sources.

A DI&M program at compressor stations can reduce methane emissions and yield significant savings by locating leaking components and focusing maintenance efforts on the largest leaks that are profitable to repair. Subsequent emissions surveys are directed towards the site components that are most likely to leak, as well as cost-effective to find and fix.

Technology Background

DI&M programs begin with a comprehensive baseline survey of all equipment components at the compressor

Economic and Environmental Benefits

Method for Reducing Natural Gas Losses	Volume of Natural Gas Savings (Mcf)	Value of Natural Gas Savings ($)			Implementation Cost ($) [1]	Payback (Months)		
		$3 per Mcf	$5 per Mcf	$7 per Mcf		$3 per Mcf	$5 per Mcf	$7 per Mcf
Identify and measure leaks. Make cost-effective repairs.	29,413 per compressor station	$88,239	$147,065	$205,891	$26,248	4 Months	3 Months	2 Months

[1] Average total cost for initial baseline survey and leak repairs.

Methane Content of Natural Gas

The average methane content of natural gas varies by natural gas industry sector. The Natural Gas STAR Program assumes the following methane content of natural gas when estimating methane savings for Partner Reported Opportunities.

Production	79 %
Processing	87 %
Transmission and Distribution	94 %

stations in the transmission system. Operators first identify leaking components and then measure the emissions rate for each leak. The repair cost for each leak is evaluated with respect to the expected gas savings and other economic criteria such as payback period. The initial leak survey results and equipment repairs are then used to direct subsequent inspection and maintenance efforts.

Leak Screening Techniques

Leak screening in a DI&M program may include all components in a comprehensive baseline survey, or may be focused only on the components that are likely to develop significant leaks. Blowdown vent stacks are normally elevated and inconvenient to access. As a result, it is difficult to test frequently for gas leakage through the blowdown valves, making them good candidates for screening as part of a DI&M program. Several leak screening techniques can be used:

★ **Soap Bubble Screening** is a fast, easy, and very low-cost leak screening technique. Soap bubble screening involves spraying a soap solution on small, accessible components such as threaded connections. Soaping is effective for locating loose fittings and connections, which can be tightened on the spot to fix the leak, and for quickly checking the tightness of a repair. Operators can screen about 100 components per hour by soaping.

★ **Electronic Screening** using small hand-held gas detectors or "sniffing" devices provides another fast and convenient way to detect accessible leaks. Electronic gas detectors are equipped with catalytic oxidation and thermal conductivity sensors designed to detect the presence of specific gases. Electronic gas detectors can be used on larger openings that cannot be screened by soaping. Electronic screening is not as fast as soap screening (averaging 50 components per hour), and pinpointing leaks can be difficult in areas with high ambient concentrations of hydrocarbon gases.

★ **Organic Vapor Analyzers (OVAs) and Toxic Vapor Analyzers (TVAs)** are portable hydrocarbon detectors that can also be used to identify leaks. An OVA is a flame ionization detector (FID), which measures the concentration of organic vapors over a range of 9 to 10,000 parts per million (ppm). A TVA combines both an FID and a photoionization detector (PID) and can measure organic vapors at concentrations exceeding 10,000 ppm. TVAs and OVAs measure the concentration of methane in the area around a leak.

★ **Infrared Cameras** work according to the principle that hydrocarbon emissions absorb infrared light in a certain wavelength. Infrared (IR) cameras use this characteristic to detect the presence of gas emissions from equipment by converting the scanned area into a moving image in real time such that the gas plumes are visible due their absorption of the IR light. Because of this, an IR camera is able to screen hundreds of components per hour. An additional advantage is the ability to screen inaccessible equipment: components in confined spaces or in elevated locations can be screened remotely from an accessible location within viewing distance. In addition, IR cameras can be hand-held for walking surveys of individual components, mounted on trucks and other vehicles for close-range inspection over moderate distances, or mounted on aircraft for aerial inspection to locate major leaks and vents over long distances. While it may not be able to pinpoint individual leaking components with low leak rates, aerial inspection is useful to screen many miles of transmissions pipelines or dispersed equipment to detect plumes from large emissions sources.

★ **Acoustic Leak Detection** uses portable acoustic screening devices designed to detect the acoustic signal that results when pressurized gas escapes through an orifice. As gas moves from a high-pressure to a low-pressure environment across a leak opening, turbulent flow produces an acoustic signal, which is detected by a hand-held sensor or probe, and read as intensity

Exhibit 1: Acoustic Leak Detection

Source: Physical Acoustics Corp.

increments on a meter. Although acoustic detectors do not measure leak rates, they provide a relative indication of leak size—a high intensity or "loud" signal corresponds to a greater leak rate. Acoustic screening devices are designed to detect either high frequency or low frequency signals.

High Frequency Acoustic Detection is best applied in noisy environments where the leaking components are accessible to a handheld sensor. As shown in Exhibit 1, an acoustic sensor is placed directly on the equipment orifice to detect the signal.

Alternatively, *Ultrasound Leak Detection* is an acoustic screening method that detects airborne ultrasonic signals in the frequency range of 20 kHz to 100 kHz. Ultrasound detectors are equipped with a handheld acoustic probe or scanner that is aimed at a potential leak source from a distance up to 100 feet. Leaks are pinpointed by listening for an increase in sound intensity through headphones. Ultrasound detectors can be sensitive to background noise, although most detectors typically provide frequency tuning capabilities so that the probe can be tuned to a specific leak in a noisy environment.

Leak Measurement Techniques

An important component of a DI&M program is measurement of the mass emissions rate or leak volume of identified leaks, so that manpower and resources are allocated only to the significant leaks that are cost-effective to repair. Four leak measurement techniques can be used:

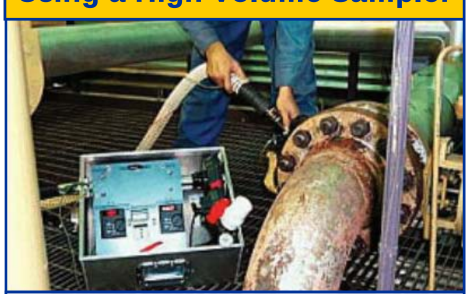
- ★ **Toxic Vapor Analyzers (TVAs)** can be used to estimate mass leak rate. The TVA-measured concentration in ppm is converted to a mass emissions rate by using a correlation equation. A major drawback to TVAs for methane leak measurement is that the correlation equations are typically not site-specific. The mass leak rates predicted by general TVA correlation equations have been shown to deviate from actual leak rates by as much as three or four orders of magnitude. Similarly, a study conducted jointly by Natural Gas STAR partners, EPA, the Gas Research Institute (GRI–now GTI, the Gas Technology Institute), and the American Gas Association (AGA) found that TVA concentration thresholds, or "cut-off" values, such as 10,000 ppm or 100,000 ppm, are ineffective for determining which methane leaks at compressor stations are cost-effective to fix. Because the use of general TVA correlation equations can increase measurement inaccuracy, the development and use of site-specific correlations will be more effective in determining actual leak rates.

- ★ **Bagging Techniques** are commonly used to measure mass emissions from equipment leaks. The leaking component or leak opening is enclosed in a "bag" or tent. An inert carrier gas such as nitrogen is conveyed through the bag at a known flow rate. Once the carrier gas attains equilibrium, a gas sample is collected from the bag and the methane concentration of the sample is measured. The mass emissions rate is calculated from the measured methane concentration of the bag sample and the flow rate of the carrier gas. Leak rate measurement using bagging techniques is a fairly accurate (within ± 10 to 15 percent), but slow process (only two or three samples per hour). Although bagging techniques are useful for direct measurement of larger leaks, bagging may not be possible for equipment components that are very large, inaccessible, and unusually shaped.

- ★ **High Volume Samplers** capture all of the emissions from a leaking component to accurately quantify leak emissions rates. Exhibit 2 shows leak measurement using a high volume sampler. Leak emissions, plus a large volume sample of the air around the leaking component, are pulled into the instrument through a vacuum sampling hose. High volume samplers are equipped with dual hydrocarbon detectors that measure the concentration of hydrocarbon gas in the captured sample, as well as the ambient hydrocarbon gas concentration. Sample measurements are corrected for the ambient hydrocarbon concentration, and a mass leak rate is calculated by multiplying the flow rate of the measured sample by the difference between the ambient gas concentration and the gas concentration in the measured sample. Methane emissions are obtained by calibrating the hydrocarbon detectors to a range of concentrations of methane-in-air.

  High volume samplers are equipped

Exhibit 2: Leak Measurement Using a High Volume Sampler



Source: Oil & Gas Journal, May 21, 2001.

with special attachments designed to ensure complete emissions capture and to prevent interference from other nearby emissions sources. High volume samplers measure leak rates up to 8 standard cubic feet per minute (scfm), a rate equivalent to 11.5 thousand cubic feet per day (Mcfd). Leak rates greater than 8 scfm must be measured using bagging techniques or flow meters. Two operators can measure thirty components per hour using a high volume sampler, compared with two to three measurements per hour using bagging techniques.

★ **Rotameters** and other flow meters are used to measure extremely large leaks that would overwhelm other instruments. Flow meters typically channel gas flow from a leak source through a calibrated tube. The flow lifts a "float bob" within the tube, indicating the leak rate. Because rotameters are bulky, these instruments work best for open-ended lines and similar components, where the entire flow can be channeled through the meter. Rotameters and other flow metering devices can supplement measurements made using bagging or high volume samplers.

Exhibit 3 summarizes the application and usage, effectiveness, and approximate cost of the leak screening and measurement techniques described above.

Decision Points

A DI&M program is implemented in four steps: (1) conduct a baseline survey; (2) record the results and identify candidates for cost-effective repair; (3) analyze the data, make the repairs, and estimate methane savings; and (4) develop a survey plan for future inspections and follow-up monitoring of leak-prone equipment.

Step 1: Conduct Baseline Survey.

A DI&M program typically begins with baseline screening to identify leaking components. As the leaking components are located, accurate leak rate measurements are obtained using bagging techniques, a high volume sampler, or TVAs that have site-specific concentration correlations. Partners have found that leak measurement using a high volume sampler is cost-effective, fast, and accurate.

The cost of the baseline survey to find and measure leaks at the 13 compressor stations included in the 1999 EPA/GRI/PRCI study was approximately $6,900 per compressor station or about $2.55 per component. A baseline survey that focuses only on leak screening is substantially less expensive. However, leak screening alone does not provide the information needed to make cost-effective repair decisions. Partners have found that follow-up surveys in an ongoing DI&M program cost 25 percent to 40 percent less than the initial survey because subsequent surveys focus only on the components that are likely to leak and are economic to repair. For some equipment components, leak screening and measurement can be accomplished most efficiently during a regularly scheduled DI&M survey program. For other components, simple and rapid leak screening can be incorporated into ongoing operation and maintenance procedures. Some operators train maintenance staff to conduct leak surveys, others hire outside consultants to conduct the baseline survey.

Exhibit 3: Screening and Measurement Techniques

Instrument/Technique	Application and Usage	Effectiveness	Approximate Capital Cost
Soap Solution	Small point sources, such as connectors.	Screening only.	Under $100
Electronic Gas Detectors	Flanges, vents, large gaps, and open-ended lines.	Screening only.	Under $1,000
Acoustic Detectors/ Ultrasound Detectors	All components. Larger leaks, pressurized gas, and inaccessible components.	Screening only.	$1,000 to $20,000 (depends on instrument sensitivity, size, associated equipment)
TVA (flame ionization detector)	All components.	Best for screening only. Measurement requires site-specific leak size correlation.	Under $10,000 (depends on instrument sensitivity/size)
Bagging	Most accessible components.	Measurement only; time-consuming.	Under $10,000 (depends on sample analysis cost)
High Volume Sampler	Most accessible components (leak rate <11.5 Mcfd)	Screening and measurement.	> $10,000
Rotameter	Very large leaks.	Measurement only.	Under $1,000

Step 2: Record Results and Identify Candidates for Repair.

Leak measurements collected in Step 1 must be evaluated to pinpoint the leaking components that are cost-effective to repair. Leaks are prioritized by comparing the value of the natural gas lost with the estimated cost in parts, labor, and equipment downtime to fix the leak. Some leaks can be fixed on the spot by simply tightening a connection. Other repairs are more complicated and require equipment downtime or new parts. For these repairs, operators may choose to attach identification markers, so that the leaks can be fixed later if the repair costs are warranted. Repair costs for components such as valves, flanges, connections, and open-ended lines are likely to be determined by the size of the component, with repairs to large components costing more than repairs to small components. Some large leaks may be found on equipment normally scheduled for routine maintenance, in which case the maintenance schedule may be advanced to repair the leak at no additional cost.

As leaks are identified and measured, operators should record the baseline leak data so that future surveys can focus on the most significant leaking components. The results of the DI&M survey can be tracked using any convenient method or format. The information that operators may choose to collect include:

- ★ An identifier for each leaking component.
- ★ The component type (for example, blowdown OEL).
- ★ The measured leak rate.
- ★ The survey date.
- ★ The estimated annual gas loss.
- ★ The estimated repair cost.

This information will direct subsequent emissions surveys, prioritize future repairs, and track the methane savings and cost-effectiveness of the DI&M program.

Understanding of fugitive methane emissions from leaking equipment at compressor stations has evolved since the mid-1990s as the result of a series of field studies sponsored by EPA, GRI, and AGA's Pipeline Research Committee International (PRCI). A study published in 1996 reported on emissions factors from emissions measurements at six compressor stations in 1994. An extension of this study published by Indaco Air Quality Services in 1995 reported on the results of emissions surveys of 27,212 components at 17 compressor stations. The third study published in 1999 by EPA, GRI, and the PRCI is the most comprehensive to date, and surveyed fugitive emissions from 34,400 components at 13 compressor stations.

The compressor stations surveyed in the 1999 EPA/GRI/PRCI study range in size from stations with 15 reciprocating compressors to stations with only two reciprocating compressors. Three of the compressor stations surveyed contain two centrifugal compressors (turbines) each, and no reciprocating compressors. Two stations contain both reciprocating compressors and turbines. The compressor stations equipped with reciprocating compressors contain an average of seven reciprocating compressors per station. Compressor stations with turbines contain an average of two turbines per station. The compressors are typically installed in parallel so that individual compressors can be on- or off-line as needed, and each compressor can be isolated and depressurized as needed for maintenance. The inlet pressure at the compressor stations typically ranges from 500 psig to 700 psig, while the outlet pressure ranges from 700 psig to 1,000 psig.

On average, the number of components surveyed per compressor station was 2,707, and 5 percent of these components were found to be leaking. The total leak rates at the 13 compressor stations ranged from 385 Mcf per year to 200,000 Mcf per year. The average total station leak rate was 41,000 Mcf per year. The largest 10 percent of leaks were found to contribute more than 90 percent of emissions. Exhibit 4 summarizes average emissions factors for the compressor station components.

At the site emitting 200,00 Mcf per year, a single source accounted for 142,000 Mcf per year of emissions—a vent from the gas system used to control compressor unloaders. This was not a significant source of gas emissions at the other sites. The compressor station with the extraordinary emissions was otherwise quite average, containing only seven reciprocating compressors. The experience of this station underscores the value of DI&M for detecting huge and costly gas leaks at compressor stations of all sizes.

Exhibit 5 illustrates the average leak repair costs for the 13 compressor stations included in the 1999 EPA/GRI/PRCI study. The repair costs include the fully loaded cost of labor as well as parts and material.

Step 3: Analyze Data and Estimate Savings.

Cost-effective repair is a critical part of successful DI&M programs because the greatest savings are achieved by targeting only those leaks that are profitable to repair. In all cases, the value of the gas saved must exceed the cost to find and fix the leak. Partners have found that an effective way to analyze baseline survey results is to create a table listing all leaks, with their associated repair cost, expected

Exhibit 4: Average Fugitive Emissions Factors for Equipment Leaks from Compressor Station Components

Component Description	ON COMPRESSOR		OFF COMPRESSOR	
COMPONENTS UNDER MAIN LINE PRESSURE[1]				
	Natural Gas Emissions Factor[2] (Mcf/yr/component)	Total Number of Components Measured	Natural Gas Emissions Factor[2] (Mcf/yr/component)	Total Number of Components Measured
Ball/Plug Valve	0.64 (±1.04)	189	5.33 (±3.71)	2,406
Blowdownn Valve			207.5 (±171.4)	57
Compressor Cylinder Joint	9.9 (±11.1)	148	—-	—-
Packing Seal—Running	865 (±247)	178		
Packing Seal—Idle	1,266 (±552)	42	—-	—-
Compressor Valve	4.1 (±3.8)	2,324		
Control Valve		—-	4.26 (±7.13)	33
Flange	0.81 (±0.89)	864	0.32 (±0.21)	2,727
Gate Valve		—-	0.61 (±0.43)	1,476
Loader Valve	17.2 (±5.6)	940		
Open-Ended Line (OEL)		—-	81.8 (±79.6)	168
Pressure Relief Valve (PRV)			57.5 (±63.2)	117
Regulator	—-	—-	0.2 (±0.2)	171
Starter Gas Vent			40.8 (±43.3)	5
Connector—Threaded	0.74 (±0.46)	1,625	0.6 (±0.3)	10.338
Centrifugal Seal—Dry			62.7 (±66.3)	14
Centrifugal Seal—Wet	—-	—-	278	2
Unit Valve[3]			3,566	12
COMPONENTS UNDER FUEL GAS PRESSURE[4]				
	ON COMPRESSOR		**OFF COMPRESSOR**	
Ball/Plug Valve	0.1 (±0.1)	414	0.51 (±0.37)	654
Control Valve			2.46 (±3.89)	69
Flange	—-	—-	0.2 (±0.2)	1,650
Fuel Valve	27.6 (±13.5)	479		
Gate Valve	—-	—-	0.43 (±0.36)	640
Open-Ended Line			2.53 (±2.19)	42
Pneumatic Vent	—-	—-	76.6 (±118.1)	14
Regulator			4.03 (±3.98)	103
Connector—Threaded	1.21 (±1.66)	2,511	0.32 (±0.16)	3,654

[1] Main line pressure range from 500 psig to 1,000 psig.
[2] Emission factors with associated 95% confidence intervals.
[3] Unit valve leakage is measured on depressurized compressors. Most of the compressors surveyed remained pressurized when taken off-line.
[4] Fuel gas pressure is typically 70 psig to 100 psig. The components on the compressor are located at the top of pistons on reciprocating compressors and are subjected to substantial vibration and heat. These components only leak when the compressor is running.

Source: Indaco Air Quality Services, Inc., 1999, Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations, Report No. PRC-246-9526.

Exhibit 5: Average Repair Cost and Payback Period for Equipment Leaks at Compressor Stations

Component Description	Type of Repair	Average Cost
Ball Valves — 1"	Replace	$120
Bull Plug on Valve	Add Teflon Tape & Tighten	$15
Compressor Blow Down	Replace	$600
Compressor Blow Down	Rebuild	$200
Compressor Valve Cap	Replace Gasket	$60
Flange — 30"	Change Gasket	$1,250
Flange — 6"	Change Gasket	$300
Fuel Valve	Replace	$200
Gate Valve	Teflon Repack	$40
Grease Port	Replace	$80
Head End of Compressor	Pull & Change Gaskets	$450
Loader Valve Flange	Replace Gasket	$80
Loader Valve Stem	Rebuild	$300
Needle Valve	Replace	$100
OEL on Valve	Grease	$45
Pig Receiver Door	Tighten	$120
Pipe Thread Fitting	Tighten, Add Teflon Tape	$30
Plug Valves	Grease	$40
Pressure Relief Valve — 1"	Replace	$1,000
PRV Flange	Tighten	$40
Rod Packing	Change Packing Rings Without Removing Rods	$750
Rod Packing	Pull Packing Case and Rods to Change Rings, Rework Packing Case	$2,600
Rod Packing	Pull Packing Case and Rods to Change Rings, Rework Packing Case & Replace Rod	$5,600
Station Blow Down	Reverse Plug	$720
Tubing	Tighten	$10
Union	Tighten	$10
Unit Valve	Clean & Inject Sealant	$70
Unit Valve — 10" Plug	Replace	$2,960

Source: Indaco Air Quality Services, Inc., 1999, Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations, Report No. PRC-246-9526.

gas savings, and expected life of the repair. Using this information, economic criteria such as net present value or payback period can be easily calculated for each leak repair. Partners can then decide which leaking components are economic to repair.

Exhibit 6 shows the total potential savings at the 13 compressor stations included in the 1999 EPA/GRI/PRCI study, based on fixing only the leaks with an estimated payback of less than one year. Repair life is assumed to be two years. For most sites the initial expense of the baseline survey and repair costs were quickly recovered in gas savings. For two sites, (station 11 and station 12) the baseline survey and repair costs never payback within the two-year repair period because the total leakage at these compressor stations is low.

This example illustrates that a comprehensive DI&M

Nelson Price Indexes

In order to account for inflation in equipment and operating & maintenance costs, Nelson-Farrar Quarterly Cost Indexes (available in the first issue of each quarter in the *Oil and Gas Journal*) are used to update costs in the Lessons Learned documents.

The "Refinery Operation Index" is used to revise operating costs while the "Machinery: Oilfield Itemized Refining Cost Index" is used to update equipment costs.

To use these indexes in the future, simply look up the most current Nelson-Farrar index number, divide by the February 2006 Nelson-Farrar index number, and, finally multiply by the appropriate costs in the Lessons Learned.

Exhibit 6: Example of Repair Costs and Net Savings for Selected Equipment Components

Station	Total Station Leak Rate (Mcf/yr)	Estimated Baseline Survey Cost[1] ($/site)	Estimated Total Repair Cost	Total Gas Saved by Leak Repair (Mcf/yr)	Value of Gas Saved Annually (at $3/Mcf)	Total Cost to Find and Fix Leaks	Year 1 Net Savings	Year 2[2] Total Net Savings	Survey and Repair Payback Period (years)
1	23,000	$7,344	$18,800	17,850	$53,550	$26,144	$27,406	$80,956	0.5
2	24,500	$9,287	$16,000	16,450	$49,350	$25,287	$24,063	$73,413	0.5
3	3,650	$3,019	$315	1,250	$3,750	$3,334	$416	$4,166	0.9
4	200,000	$10,894	$41,300	106,000	$318,000	$52,194	$265,806	$583,806	0.2
5	22,700	$9,318	$20,700	20,350	$61,050	$30,018	$31,032	$92,082	0.5
6	48,400	$8,856	$34,200	35,400	$106,200	$43,056	$63,144	$169,344	0.4
7	56,500	$9,734	$31,000	49,600	$148,800	$40,734	$108,066	$256,866	0.3
8	75,000	$6,538	$50,100	66,000	$198,000	$56,638	$141,362	$339,362	0.3
9	16,350	$6,304	$4,650	11,900	$35,700	$10,954	$24,746	$60,446	0.3
10	55,650	$5,309	$32,400	51,300	$153,900	$37,709	$116,191	$270,091	0.25
11	2,965	$6,181	$320	620	$1,860	$6,501	($4,641)	($2,781)	3.5[3]
12	385	$3,473	$100	245	$735	$3,573	($2,838)	($2,103)	4.9[3]
13	7,000	$3,473	$1,600	5,400	$16,200	$5,073	$11,127	$27,327	0.3
Total	**536,100**	**$89,730**	**$251,500**	**382,365**	**$1,147,095**	**$341,215**	**$805,820**	**$1,952,870**	**0.30**
Avg	**41,238**	**$6,902**	**$19,346**	**29,413**	**$88,239**	**$26,248**	**$61,991**	**$150,230**	**0.30**

[1] Based on estimated baseline survey cost of $2.55 per component surveyed (assumes use of high flow sampler & roatemeters for leak measurement).
[2] Assumes repair life is 2 years.
[3] For this station, a full DI&M program is not profitable. Survey modifications as described at the end of Step 3 should be investigated.
Source: Indaco Air Quality Services, 1999, Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations, Report No. PRC-246-9526.

baseline survey, which includes all of a partner's transmission compressor stations, may uncover a few individual stations where the baseline DI&M survey may not be profitable. If DI&M program is profitable for the transmission system as a whole, the information gained from the few unprofitable stations is still useful. At the very least, the unprofitable compressor stations for DI&M are identified and managed separately in future surveys. Such stations may be excluded from future DI&M surveys, surveyed less frequently, or screened with more highly focused and cost-effective techniques to reduce costs.

Step 4: Develop a Survey Plan for Future DI&M.

The final step in a DI&M program is to develop a survey plan that uses the results of the initial baseline survey to direct future inspection and maintenance practices. The DI&M program should be tailored to the needs and existing maintenance practices of the facility. An effective DI&M survey plan should include the following elements:

- ★ A list of components to be screened and tested, as well as the equipment components to be excluded from the survey.
- ★ Leak screening and measurement tools and procedures for collecting, recording, and accessing DI&M data.
- ★ A schedule for leak screening and measurement.
- ★ Economic guidelines for leak repair.
- ★ Results and analysis of previous inspection and maintenance efforts which will direct the next DI&M survey.

Operators should develop a DI&M survey schedule that achieves maximum cost-effective methane savings yet also suits the unique characteristics of a facility (e.g., the age of the compressors, the number and size of reciprocating and centrifugal compressors in service, the line pressure and the fuel gas pressure). Some partners schedule DI&M surveys based on the anticipated life of repairs made during the previous survey. Other partners base the frequency of follow up surveys on maintenance cycles or the availability of resources. Since a DI&M program is flexible, if subsequent surveys show numerous large or recurring leaks, the operator can increase the frequency of the DI&M follow-up surveys. Follow-up surveys may focus on components repaired during previous surveys, or on the classes of components identified as most likely to leak.

Decision Steps for DI&M:

1. Conduct baseline survey.
2. Record results and identify candidates for repair.
3. Analyze data and estimate savings.
4. Develop a survey plan for future DI&M.

Over time, operators can continue to fine-tune the scope and frequency of surveys as leak patterns emerge.

Estimated Savings

The potential gas savings from implementing DI&M programs at compressor stations will vary depending on the size, age, equipment, and operating characteristics of the compressor stations. Natural Gas STAR partners have found that the initial expense of a baseline survey is

One Partner's Experience: Company A

Fifteen compressor stations were surveyed annually. Total costs for the DI&M survey and repairs were $350 per station. Leaks were most commonly found at unit valves. Gas savings totaled 166,010 Mcf, averaging 11,067 Mcf per station.

Total Gas Savings	$498,030
Total Cost of Survey and Repairs	$5,250
Net Savings	**$492,780**
Year One Benefit/Cost Ratio	95:1

One Partner's Experience: Company B

Two compressor stations were surveyed quarterly. Survey costs averaged $200 per station. Leaks were most commonly found at valve stem packings, shaft seals, and flange leaks. Of 24 leaks detected, 23 were repaired at an average cost of $50. Gas savings totaled 17,080 Mcf, averaging 8,540 Mcf per station.

Total Gas Savings	$51,240
Total Survey Costs	$1,600
Total Cost of Repairs	$1,150
Net Savings	**$48,490**
Year One Benefit/Cost Ratio	19:1

One Partner's Experience: Company C

Sixty-seven compressor stations were surveyed (survey schedule included both quarterly and annual surveys, depending on the station). Leaks were most commonly found at gaskets and loose fittings, as well as at compressor valves and packing. Close to 1,150 repairs were made. Gas savings totaled 132,585 Mcf, averaging 1,978 Mcf per station.

Total Gas Savings	$397,755
Total Survey Costs	$176,175
Total Cost of Repairs	$57,180
Net Savings	**$164,400**
Year One Benefit/Cost Ratio	1.7:1

quickly recovered in gas savings.

Below are three partners' experience in implementing DI&M programs. Note that the benefit/cost ratio is positive in each case (assuming a gas price of $3 per Mcf), but varies widely from 1.7:1 to 95:1.

Lessons Learned

DI&M programs can reduce survey costs and enhance profitable leak repair. Targeting problem stations and components saves time and money needed for future surveys and helps identify priorities for a leak repair schedule. The principal lessons learned from Natural Gas STAR partners are:

- ★ A relatively small number of large leaks contribute most of a compressor station's fugitive emissions.
- ★ Screening concentrations do not accurately identify the largest leaks, nor do they provide the information needed to identify which leaks are cost-effective to repair. Effective leak measurement techniques must be used to obtain accurate leak rate data.
- ★ A cost-effective DI&M program will target the components that are most likely to leak and are economic to repair.
- ★ Natural Gas STAR partners have also found that some compressor stations are more leak-prone than others. Tracking of DI&M results may show that some compressor stations may need more frequent follow-up surveys than other stations.
- ★ Partners have found it useful to look for trends, asking questions such as "Do gate valves leak more than ball valves?" and "Does one station leak more than another?"
- ★ Re-screen leaking components after repairs are made confirms the effectiveness of the repair. A quick way to check the effectiveness of a repair is to use the soap screening method.
- ★ Institute a "quick fix" step that involves making simple repairs to simple problems (e.g., loose nut, valve not fully closed) during the survey process.
- ★ Develop a system for repairing the most severe leaks first, incorporating repair of minor leaks into regular O&M practices.
- ★ Focus future surveys on stations and components that leak most.
- ★ Record methane emissions reductions at each compressor station and include annualized reductions in Natural Gas STAR Program reports.

References

Bascom-Turner Instruments, personal communication.

Foxboro Environmental Products, personal communication.

Gas Technology Institute (formerly the Gas Research Institute), personal communication.

Henderson, Carolyn, U.S. EPA Natural Gas STAR Program, personal communication.

Howard, Touché, Indaco Air Quality Services, personal communication.

Indaco Air Quality Services, Inc., 1995, A High Flow Rate Sampling System for Measuring Leak Rates at Natural Gas Facilities. Report No. GRI-94/0257.38. Gas Technology Institute, Chicago, Illinois.

Indaco Air Quality Services, Inc., 1995, Leak Rate Measurements at U.S. Natural Gas Transmission Compressor Stations. Report No. GRI-94/0257.37. Gas Technology Institute, Chicago, Illinois.

Indaco Air Quality Services, Inc., 1999, Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations, Report No. PRC-246 -9526. PRC International (report available from the American Gas Association, Arlington, Virginia).

King Instrument Company, personal communication.

Omega Engineering, personal communication.

Physical Acoustics Corporation, personal communication.

Radian International, 1996, Methane Emissions from the Natural Gas Industry, Volume 2, Technical Report, Report No. GRI-94/0257.1. Gas Technology Institute, Chicago, Illinois.

Radian International, 1996, Methane Emissions from the Natural Gas Industry, Volume 8, Equipment Leaks, Report No. GRI-94/0257.1. Gas Technology Institute, Chicago, Illinois.

Thermo Environmental Instruments Inc., personal communication.

Tingley, Kevin, U.S. EPA Natural Gas STAR Program, personal communication.

UE Systems Inc., personal communication.

U.S. Environmental Protection Agency, 1994 – 2001, Natural Gas STAR Program, Partner Annual Reports.

U.S. Environmental Protection Agency, 1995, Natural Gas STAR Program Summary and Implementation Guide for Transmission and Distribution Partners.

**United States
Environmental Protection Agency
Air and Radiation (6202J)
1200 Pennsylvania Ave., NW
Washington, DC 20460**

**EPA430-B-03-008
October 2003**