Lessons Learned
from Natural Gas STAR Partners

Directed Inspection and Maintenance at Gas Processing Plants and Booster Stations

Executive Summary

Natural gas processing plants and their associated compressor booster stations emit an estimated 36 billion cubic feet (Bcf) of methane annually. More than 24 Bcf of total methane losses from gas plants are fugitive emissions from leaking compressors and other equipment components such as valves, connectors, seals, and open-ended lines. 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 are then made to only the leaking components that are cost-effective to fix, based on criteria such as repair cost, expected life of the repair, and payback period. Subsequent surveys are designed 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' gas processing facilities found that the majority of fugitive methane emissions are from a relatively small number of leaking components. Valves are the largest source (30 percent), followed by connectors (24 percent), and compressor seals (23 percent). The remaining 23 percent of methane losses are primarily from open-ended lines, crankcase vents, pressure relief devices, and pump seals.

Natural Gas STAR processing partners have reported significant savings and methane emissions reductions by implementing DI&M. A four-plant pilot study conducted by EPA and the Gas Technology Institute (GTI) demonstrated that instituting a DI&M program at gas processing facilities could reduce methane emissions by up to 96 percent and save up to $164,000 per plant.

Introduction

Fugitive emissions from equipment leaks account for more than 80 percent of annual natural gas losses from gas processing plants and booster stations. Emissions from continuous vents, combustion equipment, and flare systems contribute to the remaining 20 percent of gas losses and methane emissions. Natural Gas STAR partners have demonstrated that a DI&M program can profitably eliminate as much as 96 percent of gas losses and a corresponding 80 percent of methane emissions from equipment leaks. This Lessons Learned study describes the practices and technologies that can be used to successfully implement a DI&M program.

Technology Background

DI&M programs begin with a comprehensive baseline survey in which equipment components are screened to identify the leaking components. The mass emissions rates from the leaking components are measured, repair costs are estimated, and the repair payback period is calculated for each leak. Both the leak and repair cost data obtained from the baseline survey are then used to guide subsequent surveys, allowing operators to focus on components that are most likely to leak and are profitable to repair.

Economic and Environmental Benefits

Leak Source	Fugitive Methane Emissions	Method for Reducing Methane Losses	Potential Emissions Reduction	Typical Implementation Cost	Typical Partner Savings (per year per gas plant)		
					$3 per Mcf	$5 per Mcf	$7 per Mcf
Fugitive Methane Emissions from Gas Processing Plants and Booster Stations	45,000 to 128,000 Mcf/yr per gas plant	Directed Inspection & Maintenance	Up to 96 percent; average 77 percent	$14,000 to $50,000 for leak screening and measurement; $39,000 to $78,000 for repairs	$58,000 to $164,000	$97,000 to $273,000	$135,000 to $382,000

The following sections describe various leak screening and measurement techniques that can be employed as part of a DI&M program at gas processing plants and booster stations.

Exhibit 1: Toxic Vapor Analyzer

Source: Thermo Environmental Instruments Inc

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. 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. Many methane emissions sources that are cost-effective to locate, measure, and fix are generally larger than the small leaks likely to be found by soaping. However, because soap screening is rapid and of negligible cost, it can easily be incorporated into routine maintenance procedures.

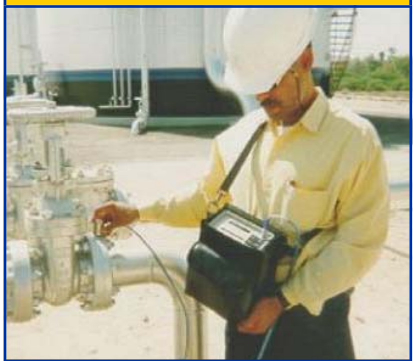
★ **Electronic Screening** using small handheld gas detectors or "sniffing" devices provides another fast and convenient way to detect accessible leaks. Electronic gas detectors have catalytic sensors designed to detect the presence of specific gases. Depending on the sensitivity of the instrument, detecting leaks in areas with elevated ambient concentrations of hydrocarbon gas can be difficult. Electronic gas detectors can be used on larger openings that cannot be screened by soaping.

★ **Organic Vapor Analyzers (OVAs) and Toxic Vapor Analyzers (TVAs)** are portable hydrocarbon detectors that can also be used to quantify 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 is a combination device containing both an FID and a photoionization detector (PID), which can measure organic vapors at concentrations exceeding 10,000 ppm. Exhibit 1 shows a typical TVA, consisting of a probe attached to a portable analytical instrument. TVAs and OVAs measure the concentration of methane in the area around a leak.

Screening is accomplished by placing a probe inlet at an opening where leakage can occur. Concentration measurements are observed as the probe is slowly moved along the interface or opening, until a maximum concentration reading is obtained. The maximum concentration is recorded as the leak screening value. Screening with TVAs is somewhat slow—approximately 40 components per hour—and the instruments require frequent calibration. In larger facilities TVAs are commonly used for volatile organic compound (VOC) leak screening, so these instruments may be readily available to screen for methane leaks.

★ **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 handheld sensor or probe, and read as intensity 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.

Exhibit 2: Acoustic Leak Detection



Source: Physical Acoustics Corp.

<u>*High Frequency Acoustic Detection*</u> is best applied in noisy environments where the leaking components are accessible to a handheld sensor. As shown in Exhibit 2, the acoustic sensor is placed directly on the equipment orifice to detect the signal. Acoustic sensors are particularly useful for detecting leaking valves where the line vent is inaccessible, such as blowdown valves and pressure relief devices connected to elevated vent stacks

Alternatively, <u>*Ultrasound Leak Detection*</u> 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 that is aimed from a distance at the potential leak source. Ultrasound detection is directional, making it possible to pinpoint the location of leaks from distances as great as 100 feet. Although ultrasound detection may be sensitive to background noise, this technique is useful for identifying gas leaks at inaccessible equipment components.

★ **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 to 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.

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 measurement techniques are commonly used:

★ **Toxic Vapor Analyzers (TVAs)** can be used to estimate mass leak rate. Concentration measurements in ppm are converted to mass emissions estimates by means of correlation equations. 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 measured concentration thresholds, or "cut-off" values, such as 10,000 ppm or 100,000 ppm are ineffective for determining which methane leaks 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 inaccessible, unusually shaped, or very large.

★ **High Volume Samplers** capture all of the emissions from a leaking component to accurately quantify leak emissions rates. Exhibit 3 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

Exhibit 3: Leak Measurement Using a High Volume Sampler

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

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 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 cubic feet per minute (scfm), a rate equivalent to 11.5 thousand cubic feet (Mcf) per day. Leak rates greater than 8 scfm must be measured using bagging techniques or flow meters. Two operators can measure 30 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 compressor seals, where the entire flow can be channeled through the meter. Rotameters and other flow metering devices can supplement surveys made using TVAs, bagging, or high volume samplers.

Exhibit 4 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 conducted 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.

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.

Step 1: Conduct Baseline Survey.

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

Prior to conducting a baseline survey, gas plant operators may not have accurate counts of their equipment components. Initial estimates of equipment components have been shown to be 40 percent lower than the actual

Exhibit 4: 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

component counts developed during a baseline survey. The number of equipment components depends upon the size and complexity of the facility. Baseline leak screening conducted by EPA and GRI at four gas processing plants found that the physical component counts ranged from approximately 14,200 components at the smallest facility to more than 56,400 components at the largest facility surveyed.

Rule of Thumb:
Initial baseline survey cost = $1.00 per component

The cost of a complete baseline screening using a high volume sampler is approximately $1.00 per component, or approximately $15,000 to $20,000 for a medium-size gas plant (in 2000 dollars). Partners have found that the cost of follow-up surveys in an ongoing DI&M program are 25 percent to 40 percent less than the initial survey. Subsequent surveys focus only on the components that are likely to leak and are cost-effective to repair. For some gas plant components, leak screening and measurement may be best accomplished during a regularly scheduled DI&M survey program. For other components, simple and rapid leak screening can be seamlessly incorporated into ongoing routine operation and maintenance procedures. Some operators train maintenance staff to conduct leak surveys, while others hire outside consultants to conduct the baseline survey.

Step 2: Record Results and Identify Candidates for Repair.

Leak measurements collected in Step 1 must be evaluated to pinpoint the leaking plant 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 warranted by the repair costs. Some large leaks might 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.

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.

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 %

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. Easy repairs should be completed on the spot, as soon as the leaks are found. Others leaks might be tagged for later attention. The results of the DI&M survey can be tracked using any convenient method or format. The information that plant operators may choose to collect include:

- An identifier for each leaking component.
- The component type (for example, blowdown OEL, 3-inch valve)
- 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.

Baseline surveys conducted on more than 100,000 equipment components at four partner-operated gas processing plants found that only 3 percent of equipment components were leaking. However, these leaking components contributed 82 percent of total methane emissions from the four plants, a total of more than 265 million cubic feet (MMcf) per year. Results indicate that components subject to vibration, high use, or temperature cycles are the most leak-prone.

Exhibit 5 shows average methane emissions measured from leaking gas plant equipment components, as well as the average leak repair costs for the various components. Exhibit 5 can be used to identify which gas plant equipment leaks are likely to be cost-effective to find and fix. For example, many of the largest leaks may be associated with compressors, but these leaks tend to be the most costly to repair. Leaking connectors, on the other hand, are inexpensive to repair. Exhibit 5 suggests that other equipment components such as flanges, valves, and open-ended lines may offer cost-effective opportunities to reduce fugitive emissions.

Step 3: Analyze Data and Estimate Savings.

By comparing the estimated repair cost to the measured leak rate, a determination can be made whether the leak is cost-effective to repair. Cost-effective repair is a critical part of a successful DI&M program because the greatest savings are achieved by targeting only those leaks that are profitable to repair.

A survey of equipment leaks and estimated repair costs at four gas plants found that for a payback of 6 months or

Exhibit 5: Average Methane Emissions Factors and Repair Costs for Selected Gas Processing Plant Components

Component Description	Gas Plant Non-Compressor (Mcf/yr/component)	Reciprocating Compressor (Mcf/yr/component)	Centrifugal Compressor (Mcf/yr/component)	Average Repair Cost ($)
Compressor Blowdown Open-Ended Line (OEL)	-	1,417	2,887	$5,000
Starter OEL	-	1,341	1,341	-
Site Blowdown OEL	742	-	-	$75
Other OEL	43	-	-	$65
Compressor Seal	-	1,440	485	$2,000
Valve	25	-	-	$130
Pressure Relief Valve	3.9	308	-	$150
Cylinder Valve Cover; Fuel Valve	-	127	63.4	$125
Connection	6.7	-	-	$25
Flange	88.2	89.7	115	$150

Source: Methane emissions factors represent weighted average of measured fugitive emissions reported in two studies: U.S. EPA, Gas Research Institute (now the Gas Technology Institute), and Radian Intl., 1996, *Methane Emissions from the Natural Gas Industry, Volume 8: Equipment Leaks;* and Gas Technology Institute and Clearstone Engineering, *Processing Plants*. Repair cost data are in 2000 dollars from GTI/Clearstone study.

Note: Methane emissions factors are adjusted to account for the average volume percent of methane in the natural gas, which is 87 percent. Similarly, emissions factors are also adjusted to account for 11 percent of compressors that are routed to a flare, plus the fraction of compressors that do not use natural gas starters.

less, 78 percent of leaking components were cost-effective to repair. In addition, 92 percent of leak repairs were found to payback in less than 1 year, and 94.5 percent of leaks paid back in less than 4 years.

Exhibit 6 provides an example of the gas savings that would be possible by fixing the 10 largest leaks at a single gas plant. This exhibit illustrates the straightforward calculation that should be made for each measured leak to determine which leaks are cost-effective to repair.

Natural Gas STAR 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 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.

Exhibits 7 and 8 illustrate the type of analysis that can be completed to determine the relative profitability of DI&M for selected types of gas plant components. The cost data, component counts, and average component emissions factors are based on the data obtained from a pilot study of DI&M at four gas processing plants. Exhibit 7 illustrates

Exhibit 6: Example of Potential Gas Savings from Fixing the Ten Largest Leaks at a Single Processing Plant

Component Description	Gas Savings (Mcf/yr)	Value of Gas Saved at $3.00 per Mcf ($/yr)	Repair Cost	Payback Period
Plug valve (leakage at bottom of valve body)	4,214	$12,642	$200	5—6 days
Union on fuel gas lines	4,052	$12,156	$100	3—4 days
Threaded connections	3,482	$10,446	$10	Immediate
Plug valve on flare line	3,030	$9,090	$200	8 days
Governor	2,572	$7,716	$200	10 days
Distance piece on recompressor cylinder	2,550	$7,650	$2,000	3 months
Open-ended line	2,320	$6,960	$60	3—4 days
Union on fuel gas line	2,204	$6,612	$100	5—6 days
Compressor seals	1,928	$5,784	$2,000	4 months
Gate valve	1,576	$4,728	$60	4—5 days
TOTAL	**27,928**	**$83,784**	**$4,930**	**21 days**

Exhibit 7: Cost Basis for Cash Flow Analysis of DI&M for Selected Gas Processing Plant Components

Type of Component		Number of Components per Gas Plant	Estimated Survey Cost	Assume 3% Leaking	Estimated Repair Cost ($/Component)	Total Repair Cost	Total Cost to Find & Fix
Connections	Compressor-Related	2135	$2,135	64	$5	$320	$2,455
	Non-Compressor Related	7664	$7,664	230	$—	$0	$7,664
	Connections Total	**9299**	**$9,799**	**294**			**$10,119**
Pressure Relief Valve	Compressor-Related	13	$13	1	$150	$150	$163
	Non-Compressor Related	48	$48	1	$150	$150	$198
	Pressure Relief Valve Total	**61**	**$61**	**2**			**$361**
OEL	Compressor Blowdown OEL	15	$15	1	$5,000	$5,000	$5,015
	Compressor Starter OEL	15	$15	1	$1,000	$1,000	$1,015
	Site Blowdown OEL	1	$1	1	$75	$75	$76
	Other OEL— Non-Compressor Related	171	$171	5	$65	$325	$496
	OEL Total	**202**	**$202**	**8**			**$6,602**
Other Valves	Compressor-Related	309	$309	9	$175	$1,575	$1,884
	Non-Compressor Related	1825	$1,825	55	$130	$7,150	$8,975
	Valve Total	**2134**	**$2,134**	**64**			**$10,859**

Assumptions: Cost data and component counts from 2000 GTI/Clearstone study. Cost for non-compressor connection repair assumes that repair is made on the spot by tightening the connection.

Exhibit 8: Example Economic Analysis of DI&M for Selected Gas Processing Plant Components

Type of Component		Total Cost to Find & Fix	Gas Savings (Mcf/Component/Yr)	Total Annual Gas Savings (Mcf)	Value of Gas Saved ($3.00/Mcf)	Cash Flow Year 1	Cash Flow Year 2	NPV	Payback Period (Years)
Connections	Compressor-Related	$2,455	6.7	429	$1,287	($1,168)	$1,287	$2	1.9
	Non-Compressor Related	$7,664	6.7	1,540	$4,621	($3,043)	$4,621	$1,053	1.6
	Connections Total	**$10,119**	**6.7**	**1,970**	**$5,909**	**($4,210)**	**$5,909**	**$1,056**	**1.7**
Pressure Relief Valve	Compressor-Related	$163	308	308	$924	$761	$924	$1,455	0.2
	Non-Compressor Related	$198	3.9	4	$12	($186)	$12	($160)	16.9
	Pressure Relief Valve Total	**$361**		**312**	**$936**	**$575**	**$936**	**$1,296**	**0.4**
OEL	Compressor Blowdown OEL	$5,015	2,152	2,152	$6,456	$1,441	$6,456	$6,456	0.8
	Compressor Starter OEL	$1,015	1,341	1,341	$4,023	$3,008	$4,023	$6,059	0.3
	Site Blowdown OEL	$76	742	742	$2,226	$2,150	$2,226	$3,794	0.3
	Other OEL—Non-Compressor Related	$496	43	215	$645	$149	$645	$669	0.8
	OEL Total	**$6,602**		**4,450**	**$13,350**	**$6,748**	**$13,350**	**$17,168**	**0.5**
Other Valves	Compressor-Related	$1,884	95	855	$2,565	$681	$2,565	$2,739	0.7
	Non-Compressor Related	$8,975	25	1,375	$4,125	($4,850)	$4,125	($1,000)	2.2
	Valve Total	**$10,859**		**2,230**	**$6,690**	**($4,169)**	**$6,690**	**$1,739**	**$10,859**

Assumptions: Average repair life is two years. Emissions data represent weighted average component emissions from EPA/GRI/Radian study and GTI/Clearstone study. NPV discount rate = 10%.

the cost basis for the initial baseline survey and repair of leaking connectors, pressure relief valves, open-ended lines (OEL), and other valves. Exhibit 8 uses the cost bases shown in Exhibit 7 for an economic analysis of DI&M for the selected equipment components.

Exhibit 8 shows that DI&M is most cost-effective for components such as open-ended lines and compressor-related pressure relief valves. These components are relatively easy to locate, screen, and measure, and have the potential for significant gas savings. Compressor and non-compressor related connections can also be cost-effective to repair. Potential economic benefit from these components, however, may be constrained due to small average leak rates and higher "find and fix" costs associated with a larger number of connections. Economic benefits are maximized when "on-the-spot" repairs, such as tightening a loose fitting, can be performed. For "other valves," the benefits of a DI&M program depend on the size of the leak, the potential gas savings, and the repair cost. Exhibit 8 suggests that DI&M is cost-effective for leaking valves associated with compressors, but may not be economic for other valves with smaller average leak rates, unless the leak survey and repairs can be incorporated into routine maintenance procedures.

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. 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 and operations of their facility. 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 company 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. 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 a DI&M program will vary depending upon the age and size of the facility, the number and types of components included in the DI&M program, and operating characteristics of the facility. Natural Gas STAR partners have found that the initial expense of a baseline survey is quickly recovered in gas savings. The following are two examples of the potential savings from a DI&M program. The first example is a joint EPA/GTI pilot study that looked at four gas plants, and the second is a study conducted by Natural Gas STAR partner, Dynegy Inc.

Pilot Study of DI&M at Four Gas Processing Plants

Four partner-operated gas plants were selected for a joint EPA/GTI pilot study of directed inspection and maintenance practices. The facilities ranged in age from 20 to 50 years. Plant throughput ranged from 60 MMcfd to 210 MMcfd. Leak screening was conducted by soaping and portable hydrocarbon gas detectors. Leaking components were tagged and leak rates were measured using a high volume gas sampler. Exhibit 9 illustrates the estimated annual volume of natural gas lost as fugitive emissions and the potential savings for these four plants from implementing DI&M. Some of the key findings of the study include:

- ★ The cost of the initial baseline survey in each pilot plant was estimated to be approximately $1.00 per

Exhibit 9: Estimated Potential Savings from DI&M at Four Gas Processing Plants, Pilot Study

Site	Site Fugitive Emissions (Mcfd)	Annual Volume of Gas Lost (Mcf/yr)	Value of Lost Gas at $3/Mcf ($/yr)	% Emissions Cost-Effective to Repair	Baseline Survey Cost ($)	Total Repair Cost ($)	Net Savings at $3/Mcf ($/yr)
1	123	44,895	$134,685	90%	$16,050	$44,725	$60,442
2	207	75,555	$226,665	95%	$14,424	$39,300	$161,608
3	352	128,480	$385,440	50%	$56,463	$77,900	$58,357
4	211	77,015	$231,045	96%	$14,168	$43,450	$164,185
TOTAL	**893**	**325,945**	**$977,835**	**77%**	**$101,105**	**$205,375**	**$444,592**

component, or $15,000 to $20,000 per gas plant.

- ★ Valves, connectors, compressor seals, and open-ended lines contributed the majority of fugitive methane emissions.
- ★ Less than 3 percent of components were found to be leaking.
- ★ Of all the leaks identified at the individual plants, 50 to 96 were cost-effective to repair.
- ★ Repair costs ranged from negligible to $5,000, depending on the type of component and the nature of the repair. Most of the repairs were estimated to have a repair life of two years.

Dynegy Study

Natural Gas STAR partner, Dynegy Inc., conducted a pilot DI&M study at two gas processing plants. Both plants are large (greater than 50 MMscfd gas throughput) and approximately 35 years old. One plant processes sweet gas; the other is a sour-gas processing facility. Leak screening was conducted using soap bubble tests, portable hydrocarbon detectors, and an ultrasound detector. Leak measurement was conducted using a high volume sampler, and bagging and rotameter measurements for leak rates that exceeded the upper limit of the high volume sampler. For each identified leak, cost-effective opportunities to reduce methane emissions were identified by comparing the cost of repair or equipment replacement with the value of the gas that would be saved in one year. Exhibit 10 summarizes the results of this study.

Exhibit 10: One Partner's Experience—Dynegy DI&M Pilot Study

Cost of initial baseline survey	$35,000 ($15,000—$20,000 per plant)
Total components surveyed in two plants	30,208
Total leaking components	1,156 (3.8%)
% of leaking components repaired	80% at one facility; 90% at the other
Total annual methane emissions reductions	100,000 Mcf/year
Annual savings (at $3/Mcf)	$300,000/year
Follow-up surveys planned (based on expected life of equipment repairs)	Once every 3 years

Lessons Learned

DI&M is a proven management practice for cost-effective reduction of methane emissions. Recent implementation of DI&M at four partner-operated gas processing plants indicate that DI&M programs have the potential to significantly reduce methane emissions from the gas processing sector. The principal lessons learned from Natural Gas STAR partners are:

- ★ The costs of the initial baseline survey can be recovered in gas savings during the first year. The cost of subsequent surveys can be reduced by focusing the survey efforts on those components that were identified through earlier studies as the most likely to leak.
- ★ Partners estimate that the cost of follow-up surveys will be 25 percent to 40 percent less because subsequent surveys will focus only on the equipment components that are likely to leak and are profitable to repair.
- ★ No two gas processing plants are alike. Opportunities for cost-effective gas savings will vary widely depending upon such factors as the age and size of the facility, types of plant components, and the operating time since the last major plant maintenance.
- ★ A combination of screening and measurement devices can be used to obtain accurate leak data. A high volume gas sampler is an effective tool for identifying and quantifying leaks.
- ★ A DI&M program should target the five categories of equipment components that contribute to the majority of methane losses: block valves, control valves, connectors, compressor seals, and open-ended lines.
- ★ If possible, partners should repair the most severe leaks first. Typically only a few leaking components are responsible for the majority of fugitive methane emissions.
- ★ 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.

- ★ Repair of minor leaks can be incorporated into regular maintenance practices. Repairs that require shutting down a system may be undertaken during the next scheduled outage.
- ★ Institute a "quick-fix" step that involves making simple repairs to simple problems (e.g., loose stem packing, valve not fully closed) during the survey process.
- ★ Screening or measuring leaking components after repairs are made confirms the effectiveness of the repair. Soap bubble screening is a quick way to check the effectiveness of a repair. Post-repair measurements with a high volume sampler allow the gas savings to be quantified and recorded.
- ★ Record methane emissions reductions for each gas processing plant and/or booster station and include annualized reductions in Natural Gas STAR Program reports.

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EPA provides the suggested methane emissions estimating methods contained in this document as a tool to develop basic methane emissions estimates only. As regulatory reporting demands a higher-level of accuracy, the methane emission estimating methods and terminology contained in this document may not conform to the Greenhouse Gas Reporting Rule, 40 CFR Part 98, Subpart W methods or those in other EPA regulations.