Reducing Emissions When Taking Compressors Off-Line

Executive Summary

Compressors are used throughout the natural gas industry to move natural gas from production and processing sites to customer distribution systems. Compressors must periodically be taken off-line for maintenance, operational stand-by, or emergency shut down testing, and as a result, methane may be released to the atmosphere from a number of sources. When compressor units are shut down, typically the high pressure gas remaining within the compressors and associated piping between isolation valves is vented to the atmosphere ('blowdown') or to a flare. In addition to blowdown emissions, a depressurized system may continue to leak gas from faulty or improperly sealed unit isolation valves.

Natural Gas STAR Partners have found that simple changes in operating practices and in the design of blowdown systems can save money and significantly reduce methane emissions by keeping systems fully or partially pressurized during shutdown. Though pressurized systems may also leak from the closed blowdown valve and from reciprocating compressor rod packing, total emissions can be significantly reduced. Four options for reducing emissions when taking compressors off-line are discussed in this paper. These include:

- ★ Keeping compressors pressurized when off-line.
- ★ Connecting blowdown vent lines to the fuel gas system and recovering all, or a portion, of the vented gas to the fuel gas system.
- ★ Installing static seals on compressor rod packing.
- ★ Installing ejectors on compressor blowdown vent lines.

Keeping compressors fully pressurized when off-line achieves immediate payback—there are no capital costs and emissions are avoided by reducing the net leakage rate. Routing blowdown vent lines to the fuel gas system or to a lower pressure gas line reduces fuel costs for the compressor or other facility equipment, in addition to

Economic and Environmental Benefits

Method for Reducing Natural Gas Losses	Volume of Natural Gas Savings (Mcf)	Value of Natural Gas Savings ($)			Implementation Cost ($)	Payback[1] (months)		
		$3 per Mcf	$5 per Mcf	$7 per Mcf		$3 per Mcf	$5 per Mcf	$7 per Mcf
Option 1. Keep compressor at pipeline pressure[2]	3,800	$11,400	$19,000	$26,600	$0	Immediate	Immediate	Immediate
Option 2. Keep compressor pressurized and route gas to fuel system[2]	5,100	$15,300	$25,500	$35,700	$2,040	2	1	1
Option 3. Keep compressor pressurized and install static seal[2]	5,000	$15,000	$25,000	$35,000	$4,900	4	3	2
Option 4. Install Ejector.[3]	780	$2,340	$3,900	$5,460	$11,644	60	36	26

[1] 10 percent discount rate. [2] Incremental savings for peak load compressors. [3] Assumes 15 Mcf per blowdown and 52 blowdowns per year; does not include capturing leakage from unit or blowdown valves.

avoiding blowdown emissions. Static seals installed on compression rods eliminate gas leaking back through the rod packing while a compressor is shutdown under pressure. An ejector uses the discharge of an adjacent compressor as motive to pump blowdown or leaked gas from a shut down compressor into the suction of an operating compressor or a fuel gas system. Benefits of these practices include fewer bulk gas releases, lower leak rates, and lower fuel costs, with a payback in most cases of less than a year.

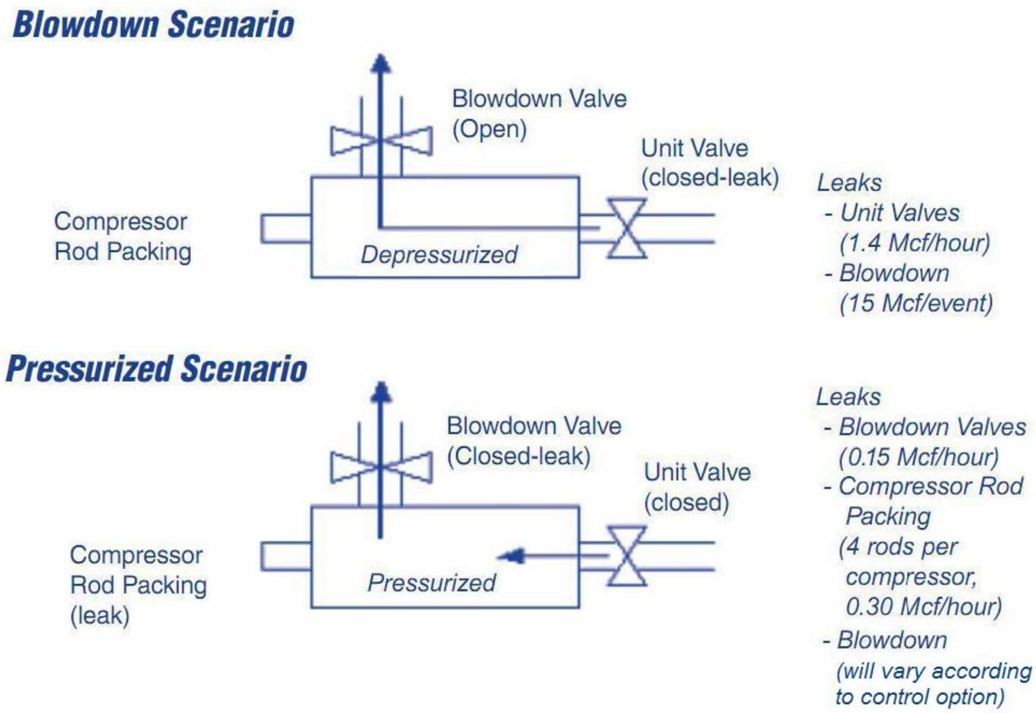
Technology Background

Compressors used throughout the natural gas system are cycled on- and off-line to meet fluctuating demand for gas. Maintenance and emergency shut down are other occasions when compressors are taken off-line. Standard practice is to blow down or vent the high pressure gas left in the compressor when it is taken off-line. While the compressor is depressurized, leakage can continue from the unit isolation valves, which are estimated to leak at an average rate of 1.4 Mcf/hour. When a compressor is fully pressurized, methane can leak from the closed blowdown valve and the compressor rod packings. Per Exhibit 1, this leakage rate from pressurized compressors is estimated to be smaller, totaling 0.45 Mcf/hour versus 1.4 Mcf/hour for a depressurized system.

The number of times a compressor is taken off-line for normal operations depends on its operating mode. Some compressors are designated as base load; these compressors are operated most of the time, and might be taken off-line only a few times per year. Down time for base load compressors averages 500 hours per year. Other compressors operate for peak load service, coming on line as demand increases and additional pipeline volumes are required. These units drop off the system (shut down) as market demand decreases. Peak load compressors may be operated for approximately 4000 hours total (less than 50 percent of the year), but cycling on- and off-line as many as 40 times per year.

The ratio of base load compressors to peak load compressors varies widely among pipeline operators because of different operating strategies, system configurations, and markets. On some pipelines, 40 percent of the compressors might be base loaded; on others, 75 percent might operate as base load. Regardless of the operating mode, significant emission savings can be gained by modifying operating practices and facility designs to minimize the amount of natural gas emitted

Exhibit 1: Compressor Diagram



Source: 1999 PRCI Final Re

during down periods.

The largest source of methane emissions associated with taking compressors off-line is from depressurizing the system by venting the gas that remains within the compressor and the piping associated with the compressor. The gas volume released during a compressor blow down depends on several factors including the size of the compressor, the pipeline pressure, and the pipe volume contained between unit isolation valves. On average, a single blowdown will release approximately 15 thousand standard cubic feet (Mcf) of gas to the atmosphere.

It should be noted that all options discussed in this paper require blowdown of a compressor before it can be taken on-line again. The main difference between the baseline scenario (blowing the compressor down on shutdown and maintaining it depressurized) and the options presented is the timing of the blowdown and the volume of the blowdown (for example, if blowdown gas is routed to the fuel system).

Unit isolation valves are another source of methane emissions from off-line depressurized compressors. Large unit valves are used to isolate the compressor from the pipeline and can leak significant amounts of methane. Unit valves have acceptable ranges of leakage specified by design tolerances for this type of valve. Unit isolation valves are periodically maintained to reduce leakage, but the limited accessibility of such valves can result in increased leakage between scheduled maintenance. A typical leak rate for unit valves is 1.4 Mcf per hour.

If the compressor is kept pressurized while off-line, emissions from compressor rod packings and blowdown valves can be observed. Seals on compressor piston rods will leak during normal operations, but this leakage increases approximately fifty percent (to about 75 scfh per rod, or 0.3 Mcf/ hour, per four-cylinder compressor) when a compressor is idle with a fully pressurized suction line. Leaks occur through gaps between the seal rings and their support cups, which are closed by the dynamic movement of the piston rod and lubricating oil (see EPA's *Lessons Learned: Reducing Methane Emissions from Compressor Rod Packing*). Vent and flare system valves can also leak from pressurized systems at a rate of 150 scfh.

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

Production	79 %
Processing	87 %
Transmission and Distribution	94 %

Natural Gas STAR Partners have significantly reduced methane emissions from compressors taken off-line by implementing changes in maintenance and operating procedures as well as installing new equipment. Following are some of the practices recommended by Natural Gas Star Partners.

1. Maintain pipeline pressure on the compressor during shutdown. As shown in Exhibit 1, leakage from the compressor seal and closed blowdown valve will increase for the pressurized system, but is still less than anticipated leakage at the unit isolation valve for a depressurized system. Partners report that total fugitive gas emissions will be reduced by as much as 68 percent, compared to leakage that would occur through the unit valve if the compressor were offline and depressurized, to approximately 0.45 Mcf/ hour for a pressurized compressor.

2. Keep the compressor at fuel gas pressure and connect to the fuel gas system. Connecting the blowdown vent or flare lines to the fuel gas system allows the gas that is purged when taking a compressor off-line to be routed to a useful outlet. The pressure of an off-line compressor equalizes to fuel line gas pressure (typically 100-150 pounds per square inch, psi). At the lower pressure, total leakage from the compressor system is reduced by more than 90 percent, compared to leakage that would occur through the unit valve if the compressor were offline and depressurized, to approximately 0.125 Mcf/hour from the compressor rod packing. Leakage across the unit valves into the compressor continues to feed the fuel system via the vent connection, rather than vent to the atmosphere or flare in the fully depressurized system.

3. *Keep the compressor at pipeline pressure and install a static seal on the compressor rods.* A static seal on the compressor rods can eliminate rod packing leaks during shutdown periods with the compressor still pressurized. A static seal is installed on each rod shaft outside the conventional packing. An automatic controller activates when the compressor is shutdown to wedge a gas-tight seal around the shaft; the controller deactivates the seal on start-up. With this equipment installed, leakage will only occur from the closed blowdown valve at about 0.15 Mcf/h with the system at high pressure. The new leakage rate would represent a reduction of 89% of the emissions that would take place if the compressor were to be kept off-line and depressurized.

4. Install Ejector. An ejector is a venturi nozzle that uses high-pressure gas as motive fluid to draw suction on a lower pressure gas source, discharging into an intermediate pressure gas stream. The ejector can be installed on vent connections up and down stream of a partly closed valve, or between the discharge and suction of a compressor which creates the necessary pressure differential. The captured gas and the motive gas are then routed to compressor suction or fuel gas system.

Economic and Environmental Benefits

Natural Gas STAR Partners can achieve substantial environmental and economic benefits by taking simple steps to avoid blowing down, or depressurizing, compressors to the atmosphere when a shut down occurs. These benefits include:

- **Fewer Bulk Gas Releases:** by routing compressor blowdown gas to the fuel gas system, operators can significantly reduce the volume of emissions while recovering a useful product. Similar results can be achieved by installing an ejector to capture the blowdown gas and route it to a useful outlet.
- **Lower Leak Rates**: maintaining compressors fully pressurized can avoid significant leaks across the unit valves of 475 Mcf per year for base load units and 3,800 Mcf per year for peak load units (see Exhibit 2). The installation of ejectors and static seals on the compressor rods when the unit is off-line will also reduce the amount of methane leaking to atmosphere.
- **Lower Fuel Costs**: routing compressor gas to the fuel system utilizes methane that would otherwise be vented or flared. This reduces fuel costs and increases the volume of gas available for sale or use.

Decision Process

When taking compressors off-line, operators can easily and cost-effectively reduce methane emissions by following these steps:

Decision Steps for Reducing Emissions When Taking Compressors Off-Line:

1. Identify blowdown alternatives.
2. Calculate quantity and value of methane emissions from the baseline (depressurized) scenario.
3. Calculate the cost and savings of alternatives.
4. Conduct economic analysis.

Step 1: Identify blowdown alternatives.

Four options previously described are available for reducing methane emissions when taking compressors off-line. The feasibility and cost of implementing each option, either singly or in combination, must be considered by operators when modifications to compressor shut down procedures are developed.

- **Option 1: Maintain pipeline pressure on the compressor during shutdown.**
- **Option 2: Route high pressure pipeline gas to fuel while keeping the compressor at fuel gas pressure.**
- **Option 3: Keep compressors pressurized and install a static seal on compressor rods.**
- **Option 4: Install Ejector to route gas to compressor suction or fuel gas system**

A prudent operating practice is to avoid fully depressurizing compressors until they are to be taken on-line again. Option 3 (installing static seals) provides added gas savings when used together with Option 1 (maintaining the compressor at pipeline pressure) by limiting fugitive gas emissions when maintaining a pressurized system. Option 4, install ejector, will recover blowdown gas that would otherwise have been vented and allow the operator to direct it to a useful outlet. In addition, Option 4 can capture leakage and route it to a useful outlet, making it possible to be implemented in combination with any of the other options.

Step 2: Calculate quantity and value of methane emissions from the baseline (depressurized) scenario.

The total methane emissions from off-line, depressurized compressors is the sum of the losses from venting the compressor and associated piping and the losses across the unit valves for the period of time the compressor is depressurized. Key inputs for calculating the total losses per compressor per year include:

- The number of blowdowns per year (B).
- The pressurized compressor's volume between unit

isolation valves (V). The volume of gas vented per blowdown depends on the compressor cavity volume, the suction and discharge bottles and piping volume between isolation valves, and the pressure. This can be calculated directly using Henry's Law (volume is inversely proportional to pressure, or $P_1V_1 = P_2V_2$). An average of 15 Mcf per blowdown is accepted as a default emissions factor by the Natural Gas STAR Program.

★ The duration of the shut-down periods (T).

★ The leakage rate at the unit valves (U). Unit valve leaks can be measured at the blowdown vent using hand-held measuring devices. Leak rates generally increase since the last maintenance of the valves. A default value of 1,400 scfh is used in this analysis.

Total emissions (TE) are calculated as: TE = B*V + T*U. The total value (TV) or cost of these emissions is TE times the price (P) of gas or TV = TE x P.

Most of this information is easily accessible from operating records and nameplate specifications, or can be estimated. Exhibit 2 presents two sample calculations of losses from the baseline scenario versus Option 1, one for a base load compressor and one from a peak load compressor.

Step 3: Calculate the cost and savings of alternatives.

The costs of each alternative include the capital investment, incremental operations and maintenance (O&M) cost, and the off-line leak rate associated with the option. Some Partner-reported costs of each option are summarized below.

★ **Option 1: Maintain pipeline pressure on the compressor during shutdown.** This option has no capital or O&M costs. When instituted, leakage occurs at the compressor rod packing (0.3 Mcf/h per compressor) and at the blowdown valve (0.15 Mcf/h), totaling approximately 0.45 Mcf/h when the compressor is fully pressurized.

★ **Option 2: Keep the compressor at fuel gas pressure and connect to the fuel gas system.** This option involves adding piping and valves to bleed gas from an idle compressor into the compressor station's fuel gas system or other low pressure sales line. Facility modification costs range between $1,470 and $2,600 per compressor. Major determinants of cost are the size of the compressor, the number of fittings, valves, and piping supports, size of piping, length of piping, and whether an automatic analyzer is installed. After the pressure in

Exhibit 2: Sample Calculations of Savings due to Implementation of Option 1 as Compared to Baseline Scenario of Maintaining Compressor Fully Depressurized

Assumptions:

	Base Load	Peak Load
Hours off-line/year	500	4,000
Unit valve leak rate (Mcf/h)	1.4	1.4
Blowdown valve leak rate (Mcf/h)	.15	.15
Rod packing leak rate (Mcf/h)	.30	.30

Sample 1: Base Load Compressor

Total Fugitive Emissions Savings = Baseline Emissions - Option 1 Emissions
= (500 hours x 1.4 Mcf/h) - (500 hours x 0.45 Mcf/h)
= 475 Mcf/year

Total Value of Saved Gas
= 475 Mcf/year x $7.00/Mcf
= $3,325 per year

Sample 2: Peak Load Compressor

Total Fugitive Emissions Savings = Baseline Emissions - Option 1 Emissions
= (4,000 hours x 1.4 Mcf/h) - (4,000 hours x 0.45 Mcf/h)
= 3,800 Mcf/year

Total Value of Saved Gas
= 3,800 Mcf/year x $7.00/Mcf
= $26,600 per year

the compressor equilibrates with the fuel line pressure, leakage from compressor rod packings falls to about 50 scfh and from the blowdown valve to about 75 scfh, totaling 0.125 Mcf/h.

★ **Option 3: Keep pressurized and install a positive static seal on compressor rods.** While technically feasible and compatible with either Option 1 or 2, Option 3 may not be cost-effective when used in conjunction with Option 2 (because leak rates are significantly lower when floating the compressor at the lower fuel line pressures). Static seals cost about $825 per rod, plus $1,600 for an automatic activation controller for the entire compressor, totaling $4,900 per four-rod compressor. With leakage from the compressor rod packing virtually eliminated, the only remaining leakage is from the blowdown valves, approximately 150 scfh.

★ **Option 4: Install Ejector.** Similar to Option 3, Option 4 is technically feasible and compatible with Options 1 and 2, as the ejector can capture gas that leaks through valves. Option 4 may not be as cost-effective when used with Option 2 (because leak rates are significantly lower when floating the compressor at lower fuel line pressures). The capital and installation costs of a typical venturi ejector are estimated to be $11,644. In addition to the ejector itself, capital expenditures include ejector block valves, piping from the blowdown vent line connections, and engineering design work to size the nozzle and expander for the site.

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.

Exhibits 3a, 3b, and 3c show sample costs and savings associated with these options.

Exhibit 3a: Sample Calculations of Savings due to Implementation of Option 2 as Compared to Baseline Scenario of Maintaining Compressor Fully Depressurized

Assumptions:

	Base Load	Peak Load
Hours off-line/year	500	4,000
Unit valve leak rate (Mcf/h)	1.4	1.4
Blowdown valve leak rate (Mcf/h)	.050	.050
Rod packing leak rate (Mcf/h)	.075	.075

Sample 1: Base Load Compressor

Total Fugitive Emissions Savings = Baseline Emissions - Option 2 Emissions	= (500 hours x 1.4 Mcf/h) - (500 hours x 0.125 Mcf/h) = 638 Mcf/year
Total Value of Saved Gas	= 638 Mcf/year x $7.00/Mcf = $4,466

Sample 2: Peak Load Compressor

Total Fugitive Emissions Savings = Baseline Emissions - Option 2 Emissions	= (4,000 hours x 1.4 Mcf/h) - (4,000 hours x 0.125 Mcf/h) = 5,100 Mcf/year
Total Value of Saved Gas	= 5,100 Mcf/year x $7.00/Mcf = $35,700

Exhibit 3b: Sample Calculations of Savings due to Implementation of Option 3 as Compared to Baseline Scenario of Maintaining Compressor Fully Depressurized

Assumptions:

	Base Load	Peak Load
Hours off-line/year	500	4,000
Unit valve leak rate (Mcf/h)	1.4	1.4
Blowdown valve leak rate (Mcf/h)	.150	.150
Rod packing leak rate (Mcf/h)	0	0

Sample 1: Base Load Compressor

Total Fugitive Emissions Savings = Baseline Emissions - Option 3 Emissions	= (500 hours x 1.4 Mcf/h) - (500 hours x 0.150 Mcf/h) = 625 Mcf/year
Total Value of Saved Gas	= 625 Mcf/year x $7.00/Mcf = $4,375

Sample 2: Peak Load Compressor

Total Fugitive Emissions Savings = Baseline Emissions - Option 3 Emissions	= (4,000 hours x 1.4 Mcf/h) - (4,000 hours x 0.150 Mcf/h) = 5,000 Mcf/year
Total Value of Saved Gas	= 5,000 Mcf/year x $7.00/Mcf = $35,000

Exhibit 3c: Sample Calculations of Savings due to Implementation of Option 4

Assumptions:

Blowdowns per year	52
Emissions per Blowdown	15 Mcf
Capital Cost	$11,644
Operating Costs	$1,575
Natural Gas Emissions Savings*	780 Mcf / yr
Total Value of Gas Saved	= 780 Mcf/year x $7.00/Mcf = $5,460

* Assumes 15 Mcf per blowdown and 52 blowdowns per year and that virtually all of the gas is captured by the ejector. Does not include capture of leaked emissions from blowdown or unit valve..

Step 4: Conduct economic analysis.

Once the quantity and value of natural gas losses and methane emissions are determined and the cost of each alternative is established, an economic analysis of the emission mitigation options is conducted. Simple payback is an industry standard economic analysis method in which the first year costs of each option are compared against the annual value of gas saved.

When maintaining pipeline pressure on compressor sets (Option 1), the net emissions savings are the difference between methane emissions from off-line leakage that occurs when the compressor is kept fully depressurized and off-line leakage that occurs when the compressor is kept fully pressurized (calculated in Exhibit 2.

Exhibit 4 presents the estimated savings of Option 1 and the incremental savings from implementing Options 2 and/or 3 in addition to Option 1. Maintaining the system under pressure while the compressor is shutdown or on standby (Option 1) demonstrates an immediate payback with no investment required. Option 2, tying vent lines into a low pressure gas pipeline while maintaining pressure on the compressor system during a shut down, is economic for both base load and peak load compressors, but significantly more attractive for peak compressors.

For Option 3, the incremental gas savings for base load compressors require just over one year to recover the facility investment but payback for peak load compressors is less than one year.

Option 4 can be implemented in combination with Options 1, 2, and 3 or individually. The cost-effectiveness of Option 4 will depend on the volume of gas vented per blowdown as

Exhibit 4: Economic Comparison of Options

	Option 1 Keep Pressurized		Option 2 Keep Pressurized and Tie to Fuel Gas		Option 3 Keep Pressurized and Install Static Seal	
	Base	Peak	Base	Peak	Base	Peak
Net Gas Savings (Mcf/yr)	475	3,800	638	5,100	625	5,000
Dollar Savings/yr[1]	$3,325	$26,600	$4,466	$35,700	$4,375	$35,000
Facilities Investment	0	0	$2,040	$2,040	$4,900	$4,900
Payback	Immediate	Immediate	6 months	1 months	14 months	2 months
IRR[2]	>100%	>100%	218%	1750%	85%	714%

[1] Assuming value of gas $7.00/Mcf
[2] 5 year life (not including annual O&M costs)

well as the number of blowdowns per year. The economic evaluation presented in Exhibit 4a assumes 15 Mcf per blowdown and 52 blowdowns per year. The economic evaluation does not account for additional gas that can be recovered from leakage through the blowdown valve or unit valve.

Exhibit 4a: Economic Evaluation of Option 4

	Option 4 Install Ejector
Net Gas Savings (Mcf/yr)[1]	780
Dollar Savings/yr[2]	$5,460
Facilities Investment	$11,644
Operating Costs	$1,575
Payback[3]	26 months
IRR[3]	37%

[1] Assuming 15 Mcf per blowdown and 52 blowdowns per year [2] Assuming value of gas $7.00/Mcf [3] 5 year life (not including annual O&M costs)

Implementation Tips

Listed below are tips that Natural Gas STAR Partners use to evaluate options and reduce emissions from off-line compressors:

★ Operators generally conduct total station maintenance turnarounds every 12 to 36 months, overhauling unit isolation valves and making major modifications such as fuel gas tie-ins. Unit valves, blowdown valves, and compressor rod packing likely experience maximum leakage rates toward the end of the operating cycle between turnarounds. Therefore, it is typically more cost-effective to make replacements during the next scheduled turnaround.

★ Safety is a priority when designing and operating natural gas facilities. Maintaining gas pressure on idle compressors and valves causes increased leakage through the equipment inside the compressor station, and the appropriate precautions must be taken within the facility for gas detection, the potential energy hazards of high pressure vessels, and adequate ventilation to prevent accumulation of leaked gases. Installing static seals on compressor rods and maintaining and selecting the appropriate valves can minimize this leakage, and, by extension, safety concerns.

★ Depressurizing off-line compressors to fuel gas is effective only where there is sufficient fuel demand to consume the gas at the rate of unit isolation valve leakage (estimated 1.4 Mcf/h).

★ Appropriate valve selection and maintenance of the seal integrity of unit isolation valves can eliminate up to 90 percent of annual emissions from the typical shutdown and blowdown practice. Repairs on these valves are expensive in terms of material and labor, as well as the gas emissions that result from the need to depressurize the entire station to access these valves.

Although the maintenance and repair cost of gas handling equipment to eliminate blow down emissions can be prohibitive in terms of valve materials and labor, when combined with better operating routines, better facility and equipment design, and elimination of unnecessary blow down practices, significant cash flow can be added to the bottom line of many operations who have economic incentives to reduce lost and unaccounted-for gas.

When assessing options for reducing emissions when taking compressors off-line, the expected price of natural gas influences decision-making. Exhibit 5a shows the impact of gas price on the economic analysis of Option 2, keeping the compressor pressurized and routing the blowdown vent to the fuel gas system.

Exhibit 5a: Impact of Gas Price on Option 2: Keep Compressor Pressurized and Route Blowdown Gas to Fuel

	$3/ Mcf	$5/ Mcf	$7/ Mcf
Value of Gas Saved	$15,300	$25,500	$35,700
Payback Period (months)	2	1	1
Internal Rate of Return (IRR)	750%	1,250%	1,750%
Net Present Value (i=10%)	$50,871	$86,022	$121,173

Exhibit 5b shows the impact of gas price on the economic analysis of Option 3, keeping the compressors pressurized and installing a static seal on the compressor rods.

Exhibit 5b: Impact of Gas Price on Option 3: Keep Compressor Pressurized and Install Static Seals

	$3 / Mcf	$5 / Mcf	$7 / Mcf
Value of Gas Saved	$15,000	$25,000	$35,000
Payback Period (months)	4	3	2
Internal Rate of Return (IRR)	306%	510%	714%
Net Present Value (i=10%)	$47,238	$81,700	$116,161

Exhibit 5c shows the impact of gas price on the economic analysis of Option 4, install ejectors.

Exhibit 5c: Impact of Gas Price on Option 4: Install Ejectors

	$3 / Mcf	$5 / Mcf	$7 / Mcf
Value of Gas Saved	$2,340	$3,900	$5,460
Payback Period (months)	60	36	26
Internal Rate of Return (IRR)	0%	20%	37%
Net Present Value (i=10%)	- $2,521	$2,854	$8,230

The impact of the gas price on the economic analysis of Option 1 is not shown since no capital investment is required to implement Option 1, making the payback immediate regardless of gas price.

Lessons Learned

Partners will find that significant emissions reductions and cost saving will result from altering routine compressor blowdown practices, and, where applicable, from rerouting vented gas. Savings accrue from retained product or displacement of fuel gas. The principal lessons learned from Natural Gas STAR Partners are:

★ Avoid depressurizing to atmosphere whenever possible. Large immediate savings can be realized at no cost by keeping off-line compressors pressurized

Case Study: An EPA Partner's Experience

With growing interest in identifying practical financial savings and reducing gas losses, Company A investigated several strategies to reduce leakage from its compressor rod packing. During a period when compressors were taken out of service, the company tied the compressor to the fuel gas system. At this lower compressor cylinder pressure, the leakage through rod packing cases and blowdown valves was reduced considerably. For 3,022 compressor cylinders (a total of 577 compressor units) operative 40 percent of the time, the total gas savings amounted to a significant 1.58 Bcf/year.

during the majority of their time off-line.

★ Educate field staff about the benefits of delaying or avoiding blowdowns.

★ Determine if individual compressors operate in base or peak load. Use this information to conduct economic analyses of Options 2 and 3.

★ Measure gas emissions from blowdown valves and individual unit isolation valves, as well as emissions from individual compressors to evaluate your actual economics of the alternatives presented.

★ Where economic, develop a schedule for retrofitting compressors with fuel gas routing systems and installing compressor rod static seals.

★ Record reductions at each compressor.

★ Reductions in methane emissions should be included in annual reports submitted as part of the Natural Gas STAR Program.

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Common Leak Detection and Measurement Devices

★ Infrared Camera
- Able to screen inaccessible equipment components
- Displays hydrocarbon emissions in a moving image using infrared properties of the hydrocarbons

★ Electronic Screening
- Equipped with catalytic oxidation and thermal conductivity sensors designed to detect certain gases
- Typically used on larger openings that cannot be screened by soaping.

★ Acoustic Leak Detection
- High frequency acoustic detectors or ultrasonic leak detectors are two types of acoustic leak detectors
- Rely on acoustic signals upstream and downstream of a possible leak to determine if gas is escaping

★ OVAs and TVAs
- Organic Vapor Analyzers (OVAs) are flame ionization detectors which measure the concentration of organic vapors over a range of 9 to 10,000 parts per million (ppm)
- Toxic Vapor Analyzers (TVAs) combine both flame ionization detectors and photoionization detectors and can measure organic vapors at concentrations exceeding 10,000 ppm

★ Calibrated Bagging
- Used to measure mass emissions from equipment leaks.
- The leaking component is enclosed in a "bag" of known volume and a timer is used to determine the time to fill the bag

★ Rotameters
- Used to measure extremely large leaks that would overwhelm other instruments.
- Ideal for open-ended lines and similar components where the entire flow can be channeled through the meter.

★ High Volume Samplers
- Capture all of the emissions from a leaking component through a vacuum sampling hose to accurately quantify leak emissions rates.
- Sample measurements are corrected for the ambient hydrocarbon concentration, and 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.

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