Methane to Markets

Methane Emissions Reduction Opportunities at Natural Gas Compressor Stations

Gazprom – EPA Technical Seminar on Methane Emission Mitigation

28 – 30 October, 2008

Methane Savings at Compressor Stations: Agenda

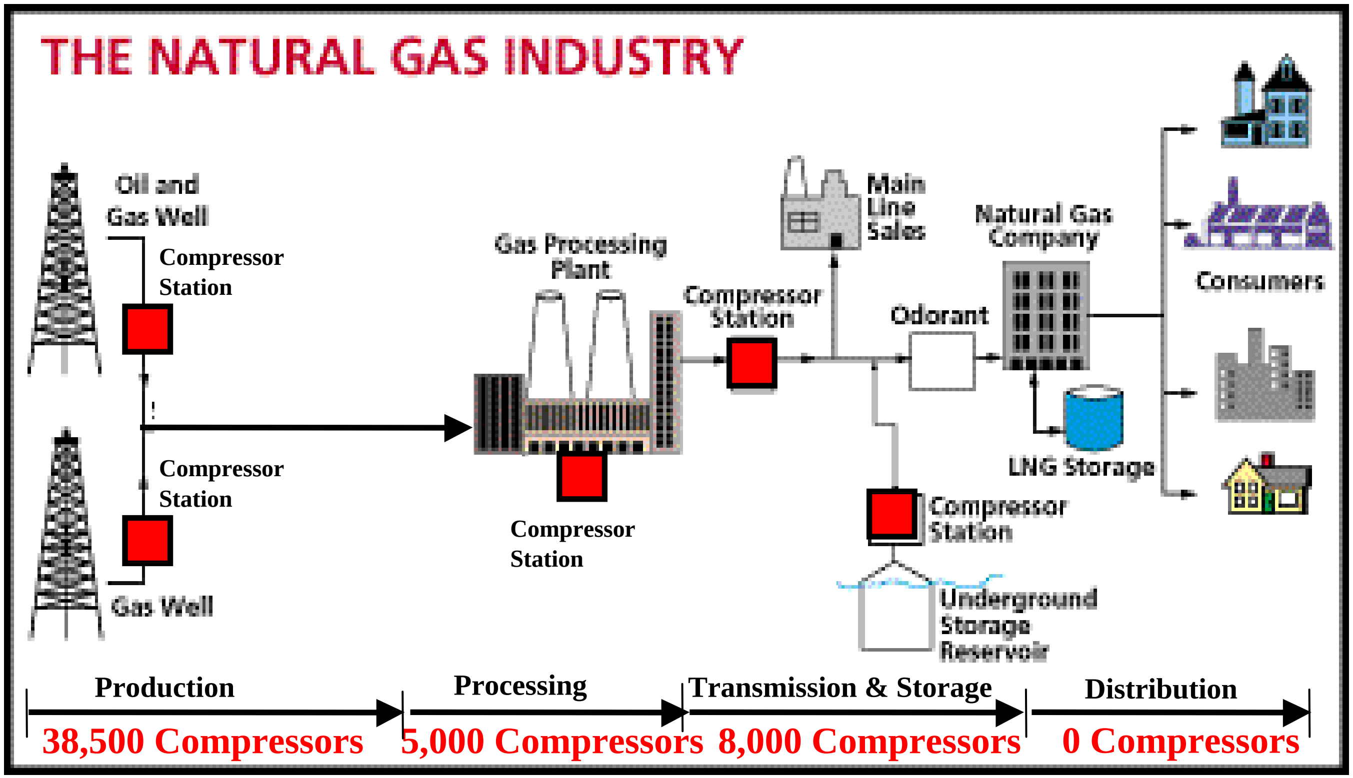
- Compressor Opportunities
  - **Replacing wet seals with dry seals in centrifugal compressors**
  - Scrubber dump valves
  - Reducing emissions when taking compressors offline
  - Economic rod packing replacement in reciprocating compressors
- Pneumatic Devices
- Discussion

Methane Savings at Compressor Stations: Economics

- All technologies and practices promoted by the Natural Gas STAR Program and Methane to Markets are proven based on successful field implementation by Partner companies
- Costs and savings represented in the following presentation are based on company specific data collected from actual projects in the U.S. and other countries; data are presented in U.S. economics
- One example estimates the economics for Russia using a range of natural gas prices and a factor to adjust for Russian capital and labor costs (slide 8 and 9) using data from the Oil and Gas Journal

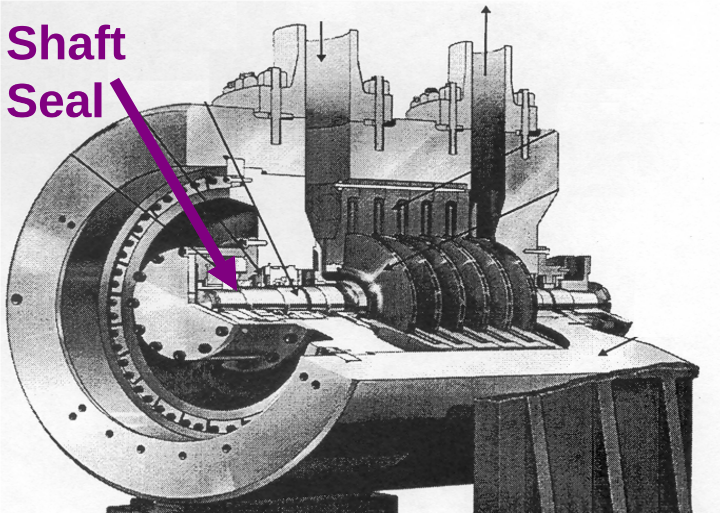
Compressor Methane Emissions
What is the problem?

- Methane emissions from the ~51,500 compressors in the U.S. natural gas industry account for 89 Billion cubic feet (Bcf) or 2,520,000 thousand cubic meters (Mcm) per year
- This represents 24% of all methane emissions from the U.S. natural gas industry



Methane Losses from Centrifugal Compressors

- Centrifugal compressor wet seals leak little gas at the seal face
  - The majority of methane emissions occur through seal oil degassing which is vented to the atmosphere
  - Seal oil degassing may vent 1.1 to 5.7 m^3/<u>minute</u> to the atmosphere
  - One Natural Gas STAR Partner reported emissions as high as 2,124 m^3/day



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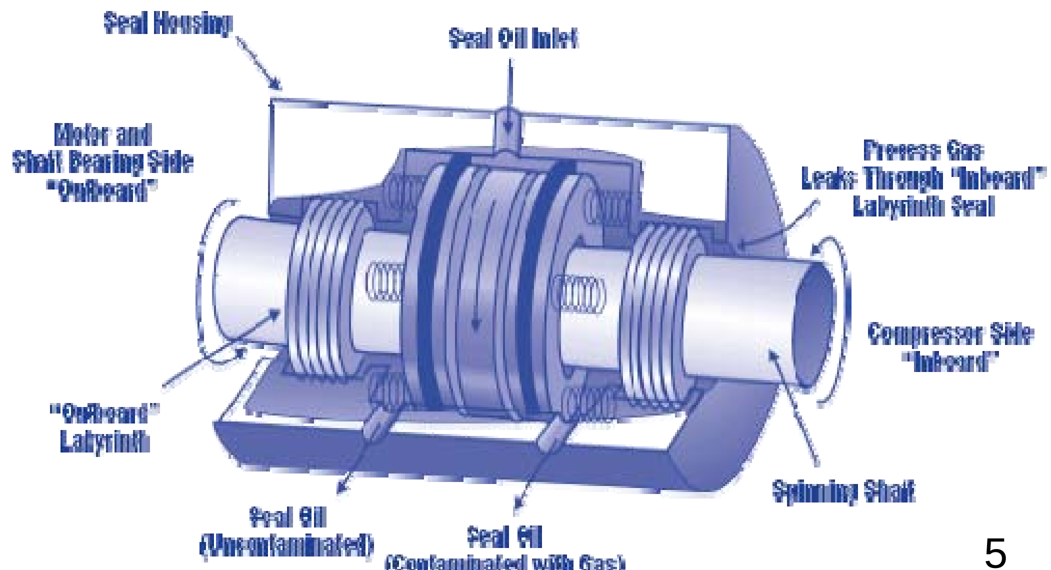
Centrifugal Compressor Wet Seals

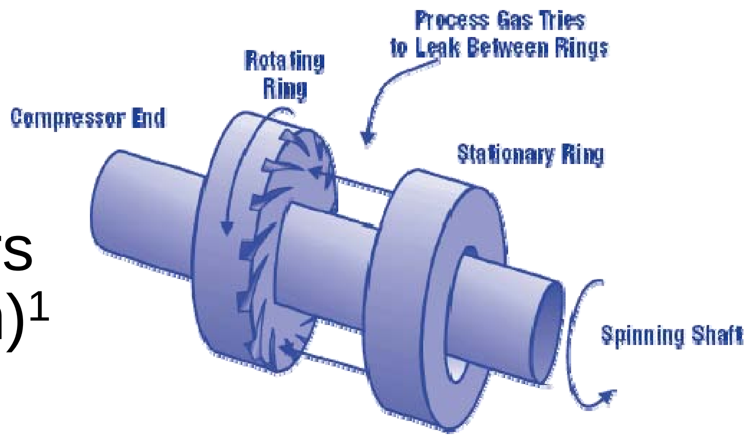
- High pressure seal oil circulates between rings around the compressor shaft
- Oil absorbs the gas on the inboard side
  - Little gas leaks through the oil seal
  - Seal oil degassing vents methane to the atmosphere

Source: PEMEX



Reduce Emissions with Dry Seals

- Dry seal springs press stationary ring in seal housing against rotating ring when compressor is not rotating
- At high rotation speed, gas is pumped between seal rings by grooves in rotating ring creating a high pressure barrier to leakage
- Only a very small amount of gas escapes through the gap
- 2 seals are often used in tandem
- Can operate for compressors up to 205 atmospheres (atm)[1] safely



[1] 205 atm = 3,000 pounds per square inch gauge (psig)

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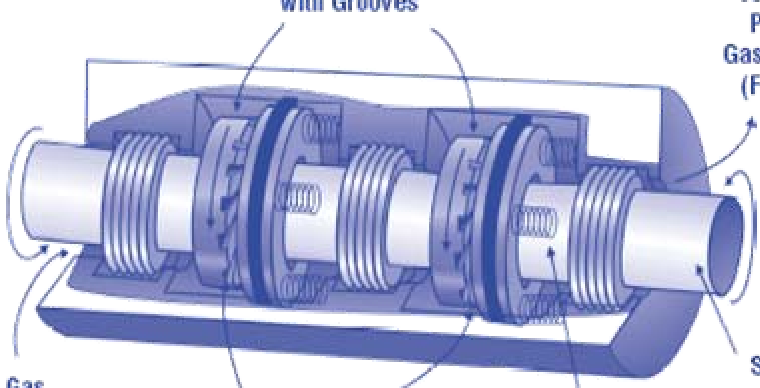
Methane Savings through Dry Seals

- Dry seals typically leak at a rate of only 0.8 to 5.1 m^3/hour (0.01 to 0.09 m^3/ minute)
  - Significantly less than the 1.1 to 5.7 m^3/minute emissions from wet seals



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Example Economic Analysis: Adjusted Russian Cost Scenario

- Replacing wet seals in a 6 inch shaft beam compressor operating 8,000 hours/year

	United States Cost Scenario		Adjusted Russian Cost Scenario[1]		High Russian Cost Scenario[2]	
	971 RUB/Mcm	9,712 RUB/Mcm	971 RUB/Mcm	9,712 RUB/Mcm	971 RUB/Mcm	9,712 RUB/Mcm
Internal Rate of Return (%)	43%	206%	38%	217%	26%	121%
Net Present Value (RUB)[3]	6,918,000	49,257,000	5,293,000	47,632,000	5,881,000	48,220,000
Payback Period (months)	24	6	26	6	32	10

- Economics are better for new installations
  - Vendors report that 90% of compressors sold to the natural gas industry are centrifugal with dry seals

[1] Gillis, Brian, et. al. *Technology drives methane emissions down, profits up*. Lead article. Oil & Gas Journal. August 13, 2007.

[2] Two times greater than the Adjusted Russian Cost Scenario

[3] Net Present Value calculated at a 10% interest rate

Detailed Calculations for the Adjusted Russian Cost Scenario

- Compare costs and savings for a 6-inch shaft beam compressor
- Costs have been altered to reflect adjusted Russian cost scenario[1]

	Gas Price: 971 RUB/Mcm		Gas Price: 9,712 RUB/Mcm	
Cost Category	Dry Seal (RUB)	Wet Seal (RUB)	Dry Seal (RUB)	Wet Seal (RUB)
Implementation Costs[2]				
Seal costs (2 dry @ 298,300 RUB/shaft-inch, w/testing)	3,579,000		3,579,000	
Seal costs (2 wet @ 149,200 RUB/shaft-inch)		1,790,000		1,790,000
Other costs (engineering, equipment installation)	3,579,000		3,579,000	
Total Implementation Costs	7,158,000	1,790,000	7,158,000	1,790,000
Annual O&M	311,000	1,576,000	311,000	1,576,000
Annual methane savings (8,000 hours/year)				
2 dry seals at a total of 10 m^3/hour	80,000		793,000	
2 wet seals at total 170 m^3/hour		1,321,000		13,203,000
Total Costs Over 5-Year Period (RUB):	9,108,000	16,268,000	12,672,000	75,649,000
Total Dry Seal Savings Over 5 Years:				
Savings (RUB)	7,161,000		63,007,000	
Methane Emissions Reductions (Mcm) (at 1,278 Mcm/year)	6,389		6,389	

[1] Gillis, Brian, et. al. *Technology drives methane emissions down, profits up*. Lead article. Oil & Gas Journal. August 13, 2007.

[2] Flowserve Corporation (updated costs and savings)

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Industry Experience – PEMEX (Mexican Production Company)

- PEMEX had 46 compressors with wet seals at its PGPB production site
- Converted three to dry seals
  - Cost $444,000/compressor
  - Saves 580,500 m^3/compressor/year
  - Saves $126,690/compressor/year in gas
- 3.5 year payback from gas savings alone
- Plans for future dry seal installations

Source: PEMEX

Finding More Opportunities

- Partners are identifying other technologies and practices to reduce emissions
  - BP-Indonesia degasses wet seal oil to a low pressure fuel gas boiler, capturing most emissions as fuel
    - Reduces expensive implementation costs of replacing with dry seals
  - TransCanada has successfully conducted pilot studies on the use of an ejector to recover dry seal leakage

Source: TransCanada

Supersonic Gas Injector: TransCanada (Canadian Transmission Company)

- Developed for capturing very low pressure vent gases and re-injection into a high pressure gas stream without the use of rotating machinery
- Savings
  - 113,000 m^3/year of gas savings from one compressor
  - Natural gas worth $28,000/year/unit @$7/Mcf GHG emissions
  - Zero operating cost

Source: TransCanada

Methane Savings at Compressor Stations: Agenda

- Compressor Opportunities
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  - **Scrubber dump valves**
  - Reducing emissions when taking compressors offline
  - Economic rod packing replacement in reciprocating compressors
- Pneumatic Devices
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Scrubber Dump Valves, Unit Valves, Pressure Relief Valves

- Major sources of leakage identified from Research in mid 1990's (GRI, EPA, PRCI) are the same in today.
  - Compressor seals, unit valves, scrubber dump valves and blow down valves.
- Most often missed savings opportunities occur from scrubber dump valves leaking through condensate tanks.
  - Easy access, low cost repair, huge savings potential.

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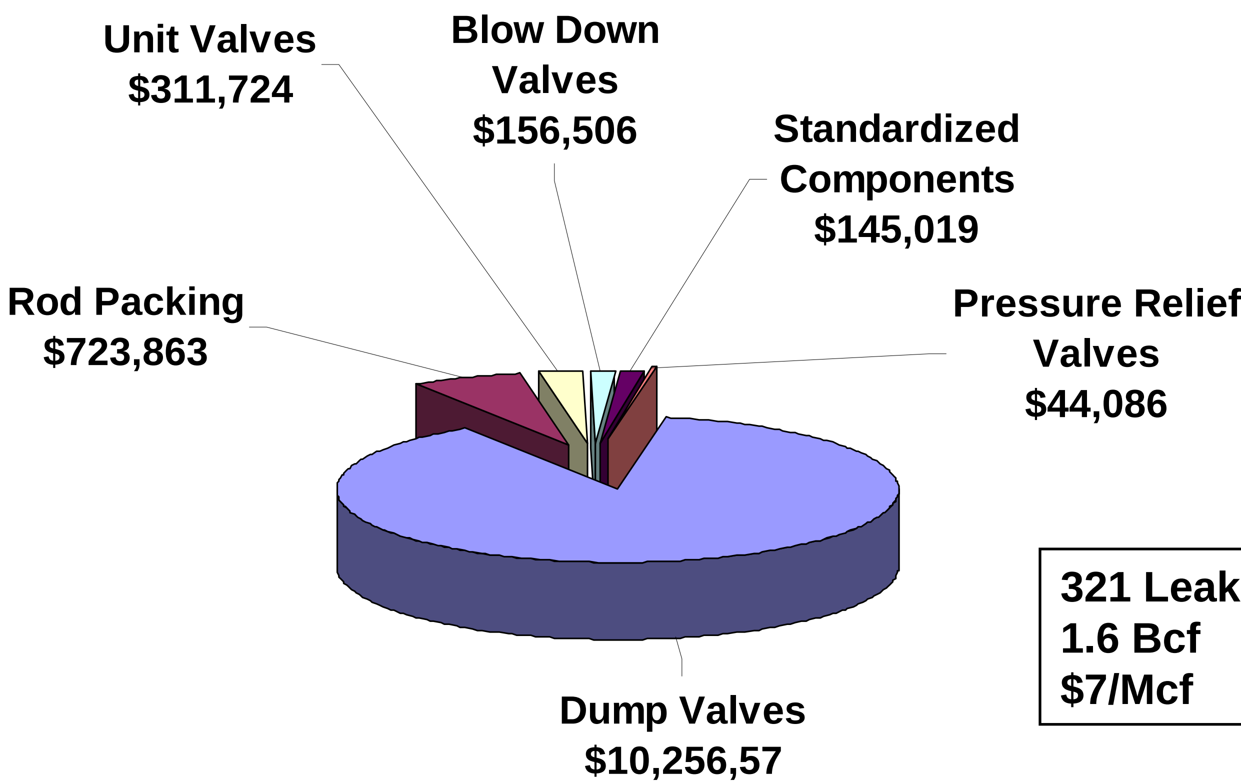
Natural Gas Losses by Equipment Type

- Dump valves represent one of the largest sources of methane leaks at compressor stations

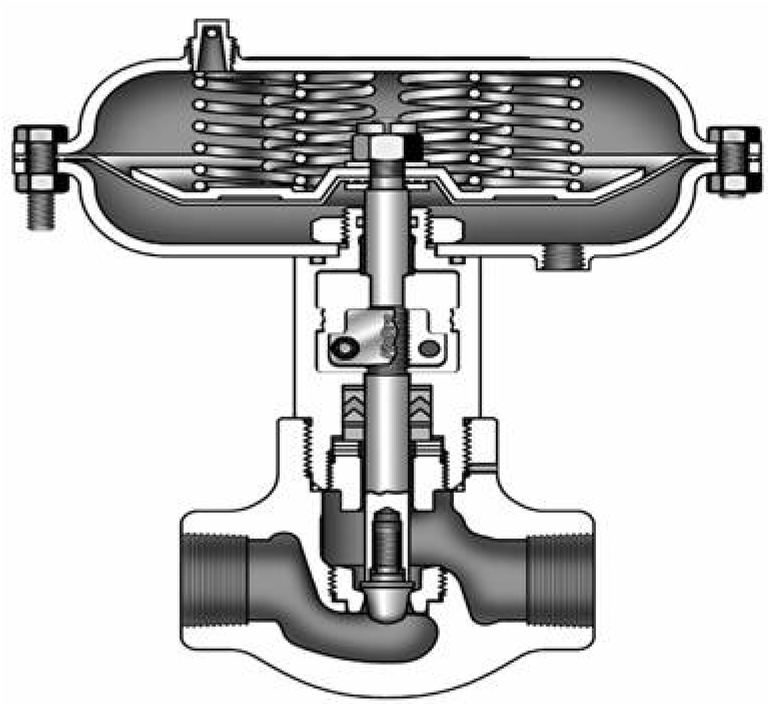


321 Leak Sources
1.6 Bcf
$7/Mcf

Data Source: Heath Consultants Inc. 2005 (U.S. measurements)

Scrubber Dump Valves

- Improper closing of dump valves in compressor scrubbers can lead to gas venting from tanks
- Causes
  - Seat repair/damage
  - Debris
  - Over flush
- Detection and measurement methods
  - Infrared Leak Detection
  - Sonic
  - Adiabatic expansion (ice)
  - Measurement charts
  - High volume sampler



Source: Northern Natural Gas

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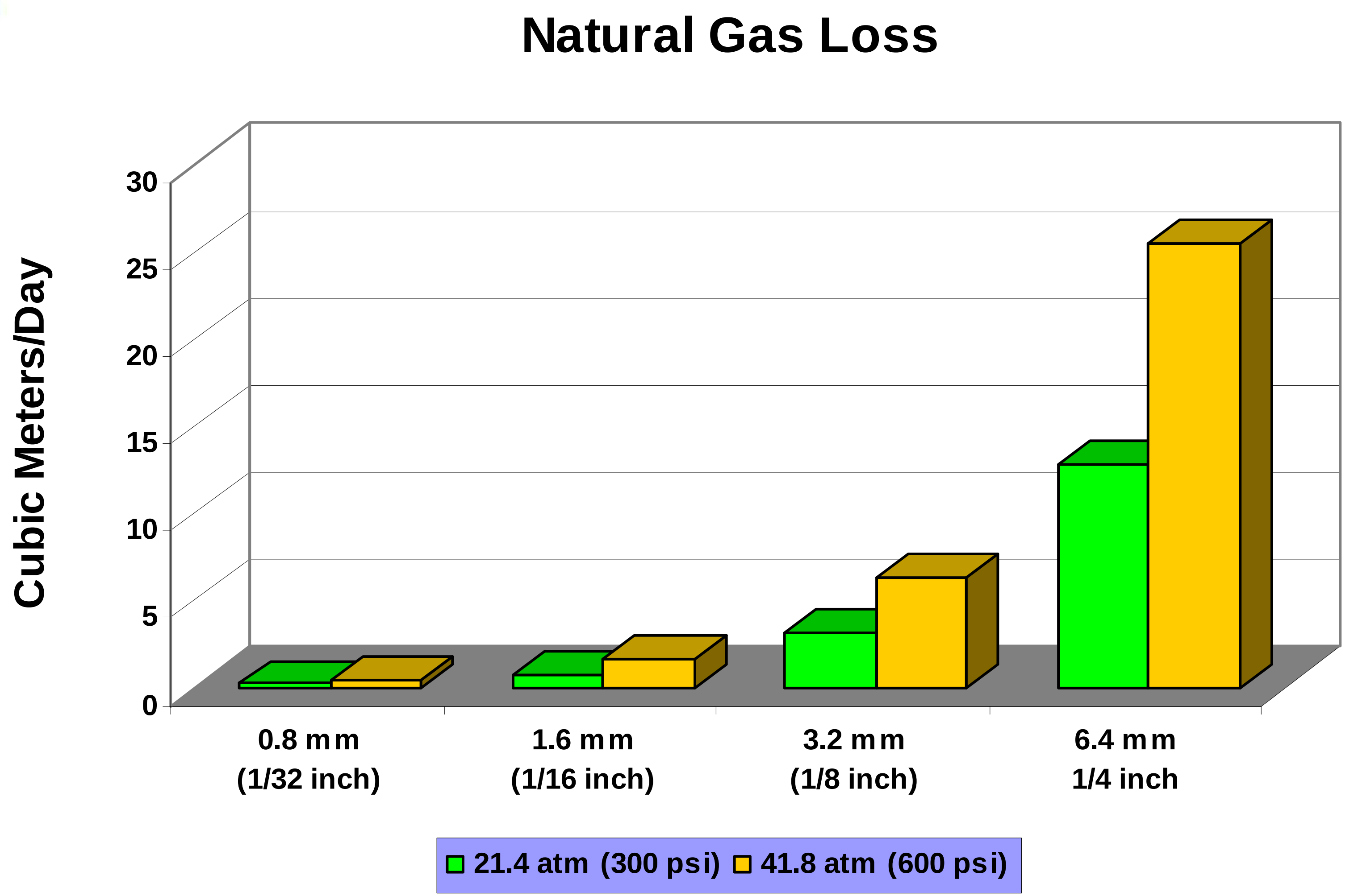
Northern Natural Gas Experience (U.S. Transmission Company): Dump Valves

- Separator Dump Valve Leak

Source: Northern Natural Gas

IR leak detection using FLIR GasFinIR®

Northern Natural Gas: Dump Valve Gas Losses



Northern Natural Gas: Repaired Dump Valve

IR leak detection using FLIR GasFinIR®

Northern Natural Gas: Separator Dump Valve Data

- 435 dump valves: 3.7 m^3/hour
- 41 @ one station
- Inspection
  - Daily rounds – feel & listen
  - Trim inspection & repair

- 435 dump valves: 0.3 m^3/hour
- Volume from dumping operation – flash gas
- Purge volume

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Compressors Offline: What is the Problem?

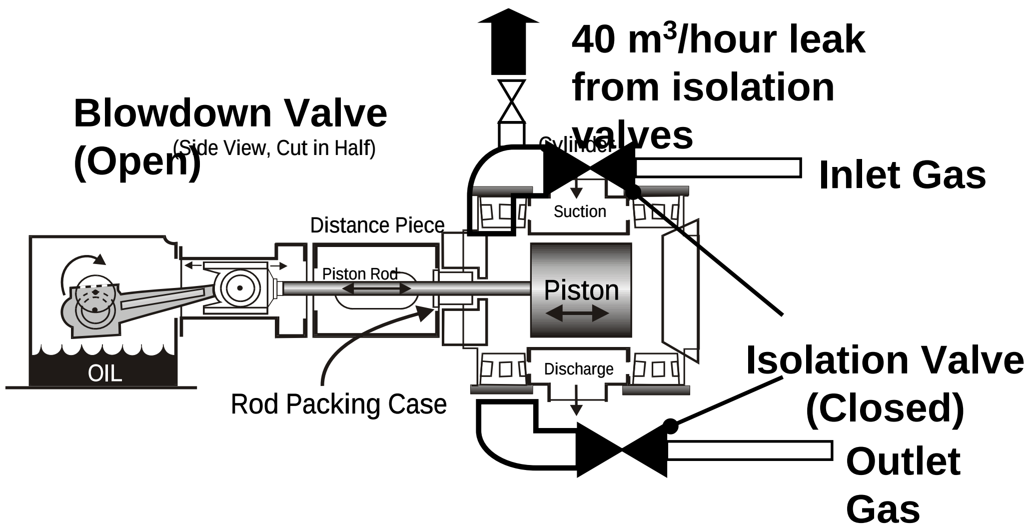
- Natural gas compressors cycled on- and off-line to match fluctuating gas demand
  - Peak and base load compressors
- Standard practice is to blow down (depressurize) off-line compressors
  - One reciprocating compressor blowdown vents 425 m^3 gas to atmosphere on average
- Isolation valves
  - Leak about 40 m^3/hour on average through open blowdown vents

Compressors Offline: Methane Recovery

- Principles of reducing emissions from offline compressors applicable to both reciprocating and centrifugal compressor
- Volume of losses vary for reciprocating and centrifugals
  - Blowdown volumes larger for reciprocating
  - Isolation valve leakage similar in magnitude
  - Compressor seal leakage similar in magnitude
- Following example show methane emissions savings from a reciprocating compressor

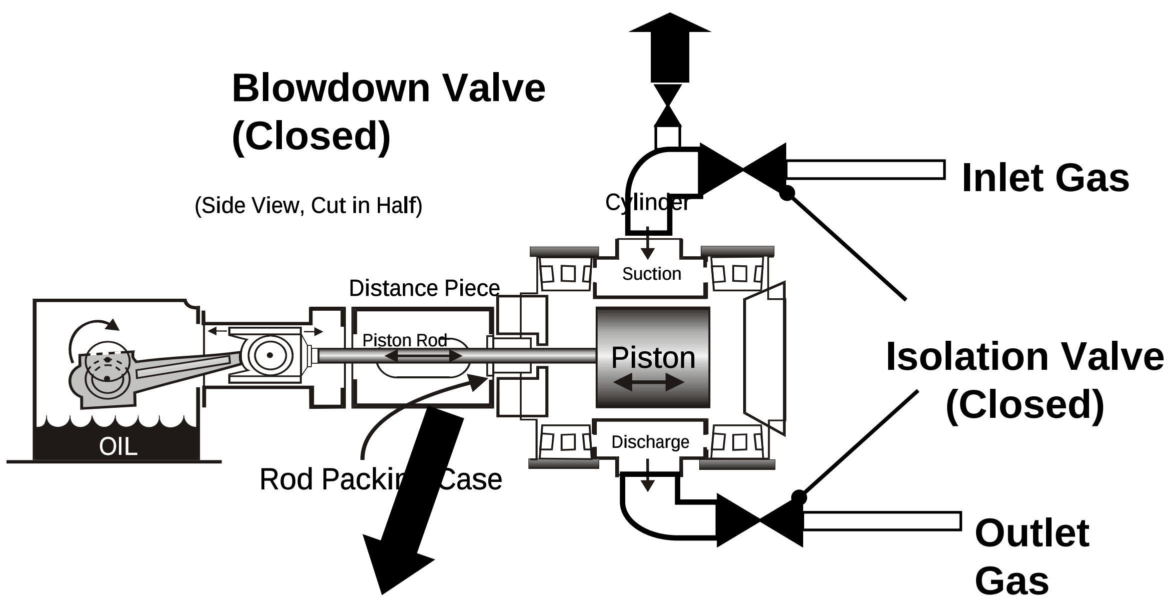
Basic Reciprocating Compressor Schematic

- Depressurized



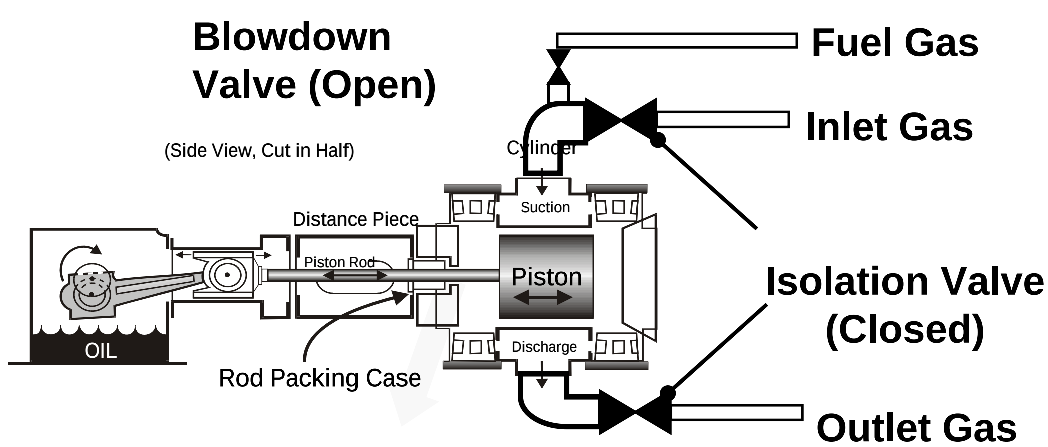
Methane Recovery - Option 1

- Keep off-line compressors pressurized
  - Requires no facility modifications
  - Eliminates methane vents
  - Seal leak higher by 8.5 m^3/hour
  - Reduces fugitive methane losses by 27 m^3/hour (68%)



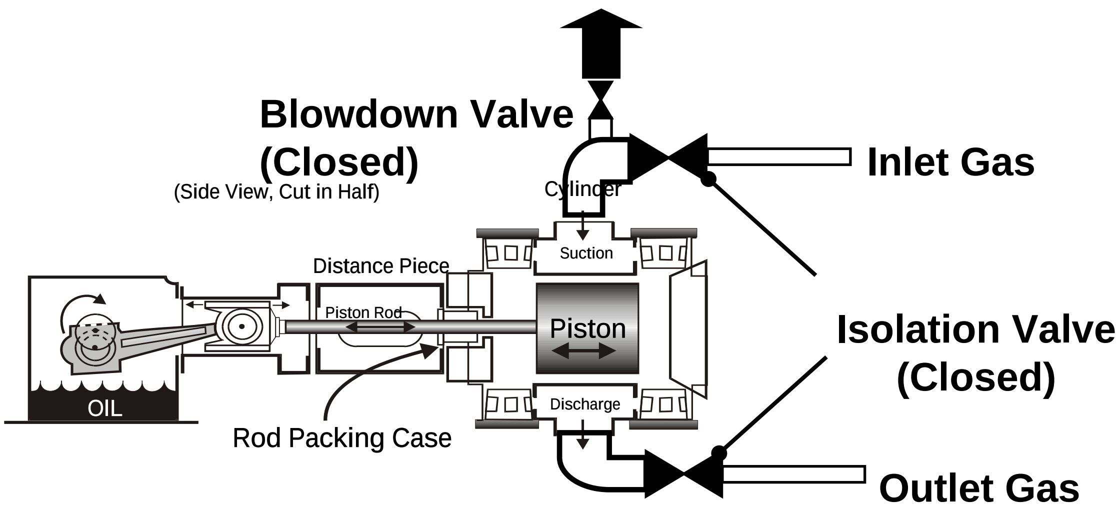
Methane Recovery - Option 2

- Route off-line compressor gas to fuel
  - Connect blowdown vent to fuel gas system
  - Off-line compressor equalizes to fuel gas pressure
  - (7.8 to 11.2 atm)
  - Eliminates methane vents
  - Seal leak higher by 3.5 m^3/hour
  - Reduces fugitive methane losses by 36 m^3/hour (91%)



Methane Recovery - Option 3

- Keep pressurized and install a static seal
  - Automatic controller activates rod packing seal on shutdown and removes seal on startup
  - Closed blowdown valve leaks
  - Eliminates leaks from off-line compressor seals
  - Reduces fugitive methane losses by 35 m^3/hour (89%)



Compressors Offline: Calculate Methane Emissions

- Blowdown losses = (# blowdowns) x (425 m^3)[1]
- Fugitive losses = (# offline hours) x (40 m^3/hour)[1]

- Total losses = blowdown + fugitive savings

- Example for base load compressor:
  - 2 blowdowns/yr x 425 m^3
  - 1,752 offline hours x 40 m^3/hour = 70,900 m^3/year

[1]EPA default values

Compressors Offline: Calculate Costs

- Option 1: Do not blow down
  - No capital costs
  - No O&M costs
- Option 2: Route to fuel gas system
  - Add pipes and valves connecting blowdown vent to fuel gas system
  - Upgrade costs range from $1,000 to $2,000 per compressor

Compressors Offline: Calculate Costs

- Option 3: Do not blow down and install static seal
  - Seals cost $675 per rod
  - Seal controller costs $1,500 per compressor
  - Less cost-effective in conjunction with Option 2

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Compressors Offline: Is Recovery Profitable?

- Costs and Savings

	Option 1 Keep Pressurized	Option 2 Keep Pressurized and Tie to Fuel Gas	Option 3 Keep Pressurized and Install Static Seal
Capital	None	$ 1,700/compressor	$ 4,100/compressor
Off-line Leakage			
Baseload	6,400 m^3/year $1,600	1,800 m^3/year $400	2,100 m^3/year $500
Peak Load	51,000 m^3/year $12,600	14,100 m^3/year $3,500	17,000 m^3/year $4,200
Note: Baseload scenario assumes compressor is off-line 500 hours/year; peak load scenario assumes compressor is off-line 4,000 hours/year. Gas cost is $7/Mcf.			

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Compressors Offline: Economic Analysis

- Peak load options more economical due to more blowdowns and offline time

	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 (m^3/year)	14,700	124,600	+5,900	+38,100	+4,200	+34,000
Dollar Savings/year[1]	$ 3,600	$ 30,800	$ 1,500	$ 9,400	$ 1,100	$ 8,400
Facilities Investment	0	0	$ 1,700	$ 1,700	$ 4,100	$ 4,100
Payback	Immediate	Immediate	1 yr	2 months	4 yrs	6 months
IRR[2]	>100%	>100%	82%	560%	9%	207%

[1] **Assuming value of gas is $7/Mcf**

[2] **5 year life (not including annual O&M costs)**

Compressors Offline: Lessons Learned

- Avoid depressuring whenever possible
  - Immediate benefits with no investment
- Educate field staff about benefits
- Identify compressor loads to conduct economic analysis
- Develop schedule for installing fuel gas routing systems
- Record savings at each compressor

Methane Savings at Compressor Stations: Agenda

- Compressor Opportunities
  - Replacing wet seals with dry seals in centrifugal compressors
  - Scrubber dump valves
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  - **Economic rod packing replacement in reciprocating compressors**
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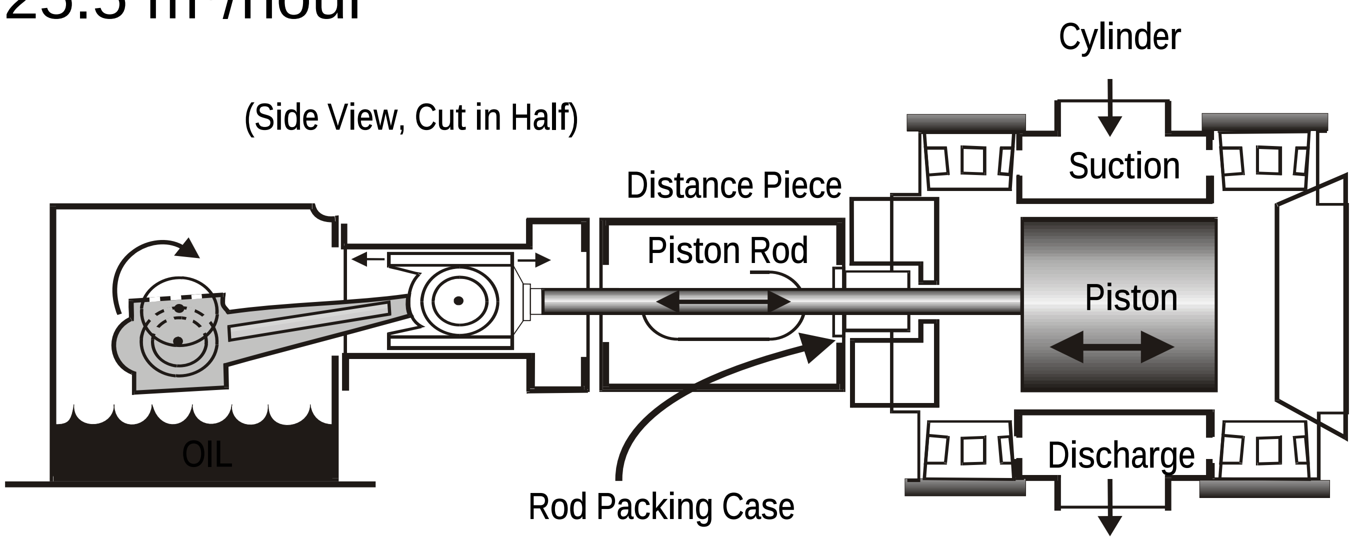
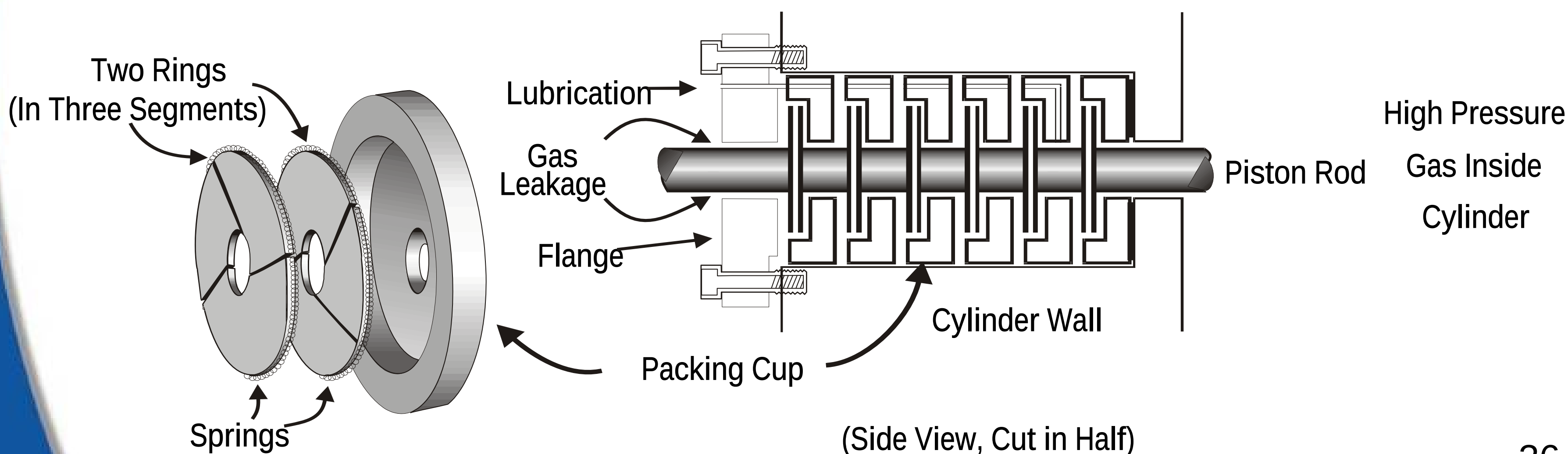
Methane Losses from Reciprocating Compressors

- Reciprocating compressor rod packing leaks some gas by design
  - Newly installed packing may leak 0.3 to 1.7 m^3/hour
  - Worn packing has been reported to leak up to 25.5 m^3/hour



Reciprocating Compressor Rod Packing

- A series of flexible rings fit around the shaft to prevent leakage
- Leakage may still occur through nose gasket, between packing cups, around the rings, and between rings and shaft



Impediments to Proper Sealing

Ways packing case can leak

- Nose gasket
- Packing to rod
- Packing to cup
- Packing to packing
- Cup to cup

What makes packing leak?

- Dirt or foreign matter (trash)
- Worn rod (.015 mm/per cm dia.)
- Insufficient/too much lubrication
- Packing cup out of tolerance ($\leq$ 0.05 mm)
- Improper break-in on startup
- Liquids (dilutes oil)
- Incorrect packing installed (backward or wrong type/style)

Methane Losses from Rod Packing

Emission from Running Compressor	24,600	m^3/year-packing
Emission from Idle/Pressurized Compressor	36,000	m^3/year-packing
Leakage from Packing Cup	19,500	m^3/year-packing
Leakage from Distance Piece	8,500	m^3/year-packing

Leakage from Rod Packing on Running Compressors				
Packing Type	Bronze	Bronze/Steel	Bronze/Teflon	Teflon
Leak Rate (m^3/year)	17,300	15,700	37,300	5,900

Leakage from Rod Packing on Idle/Pressurized Compressors				
Packing Type	Bronze	Bronze/Steel	Bronze/Teflon	Teflon
Leak Rate (m^3/year)	17,400	N/A	36,500	5,400

Source: Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations – PRCI/ GRI/ EPA PR-246-9526

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Steps to Determine Economic Replacement

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- Measure rod packing leakage
  - When new packing installed – after worn-in
  - Periodically afterwards
- Determine cost of packing replacement
- Determine economic replacement threshold
  - Partners can determine economic threshold for all replacements
  - This is a capital recovery economic calculation
- Replace packing when leak reduction expected will pay back cost

Economic Replacement Threshold (m^3/hour) =

$$\frac{CR * DF * 1{,}000}{(H * GP)}$$

Where:

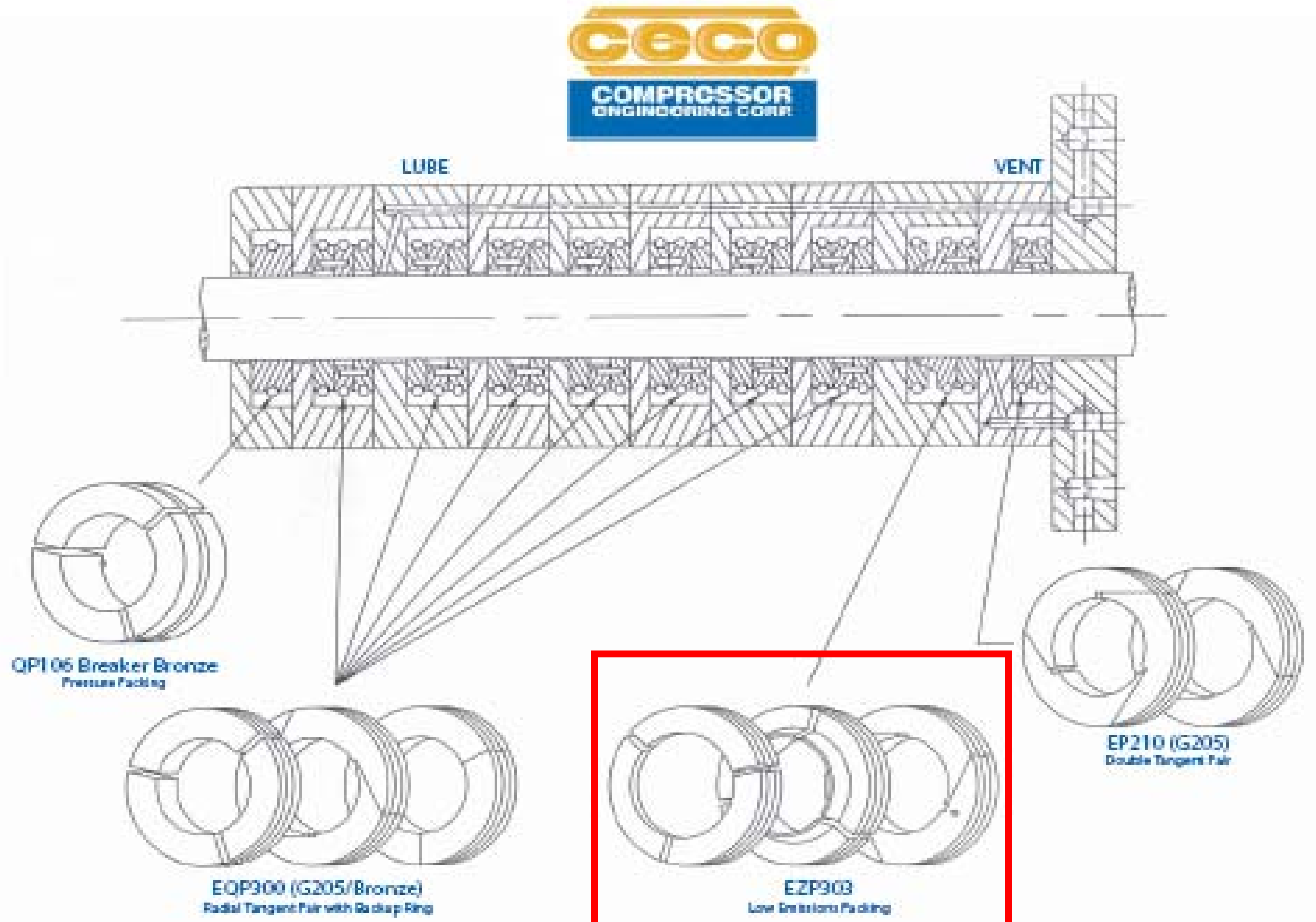
CR = Cost of replacement ($)
DF = Discount factor at interest *i* =
H = Hours of compressor operation per year
GP = Gas price ($/thousand cubic meters)

$$DF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

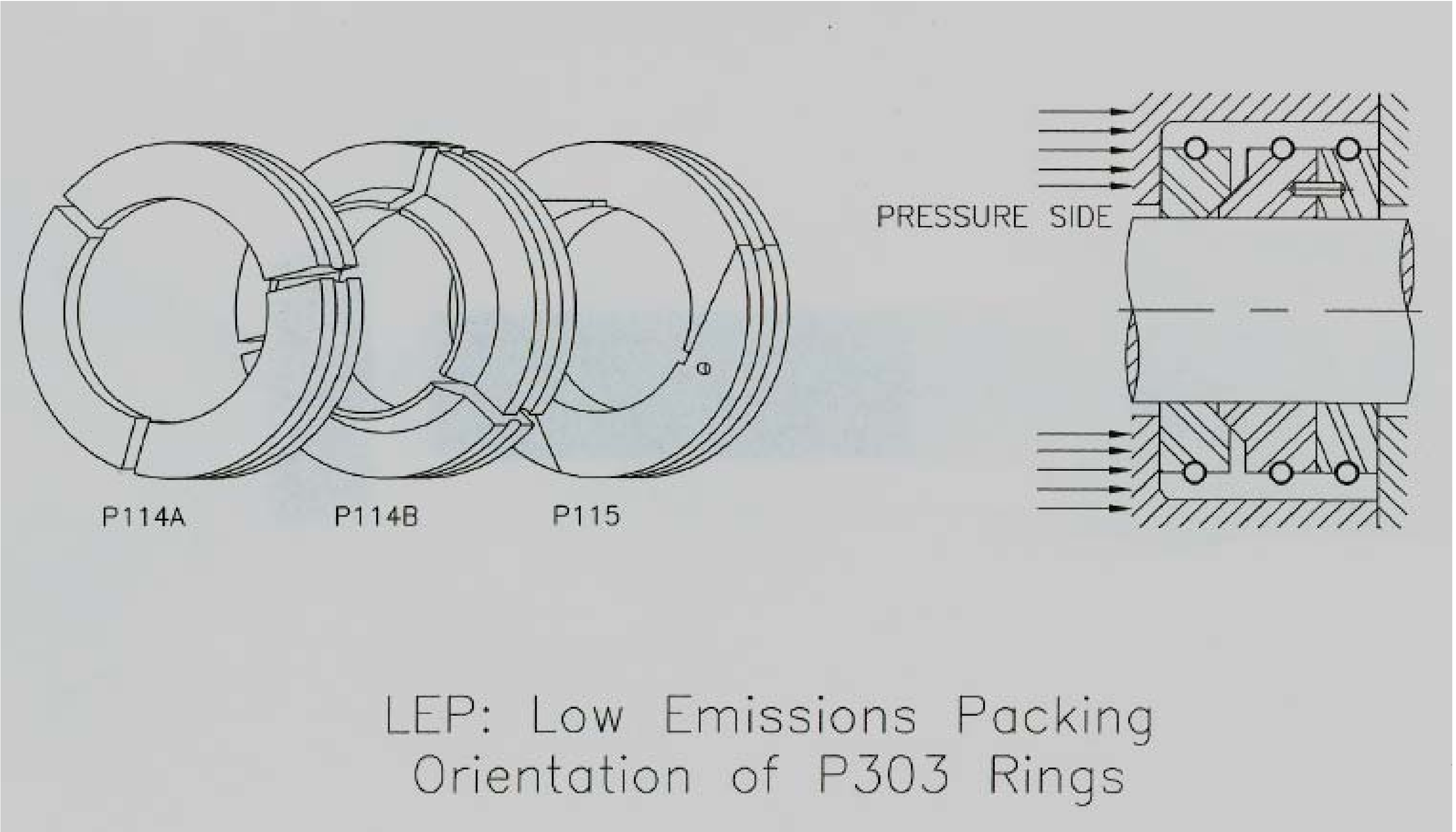
Low Emission Packing

- The side load eliminates clearance and maintains positive seal on cup face
- LEP is a static seal, not a dynamic seal. No pressure is required to activate the packing
- This design works in existing packing case with limited to no modifications required

LEP Packing Configuration



Orientation in Cup



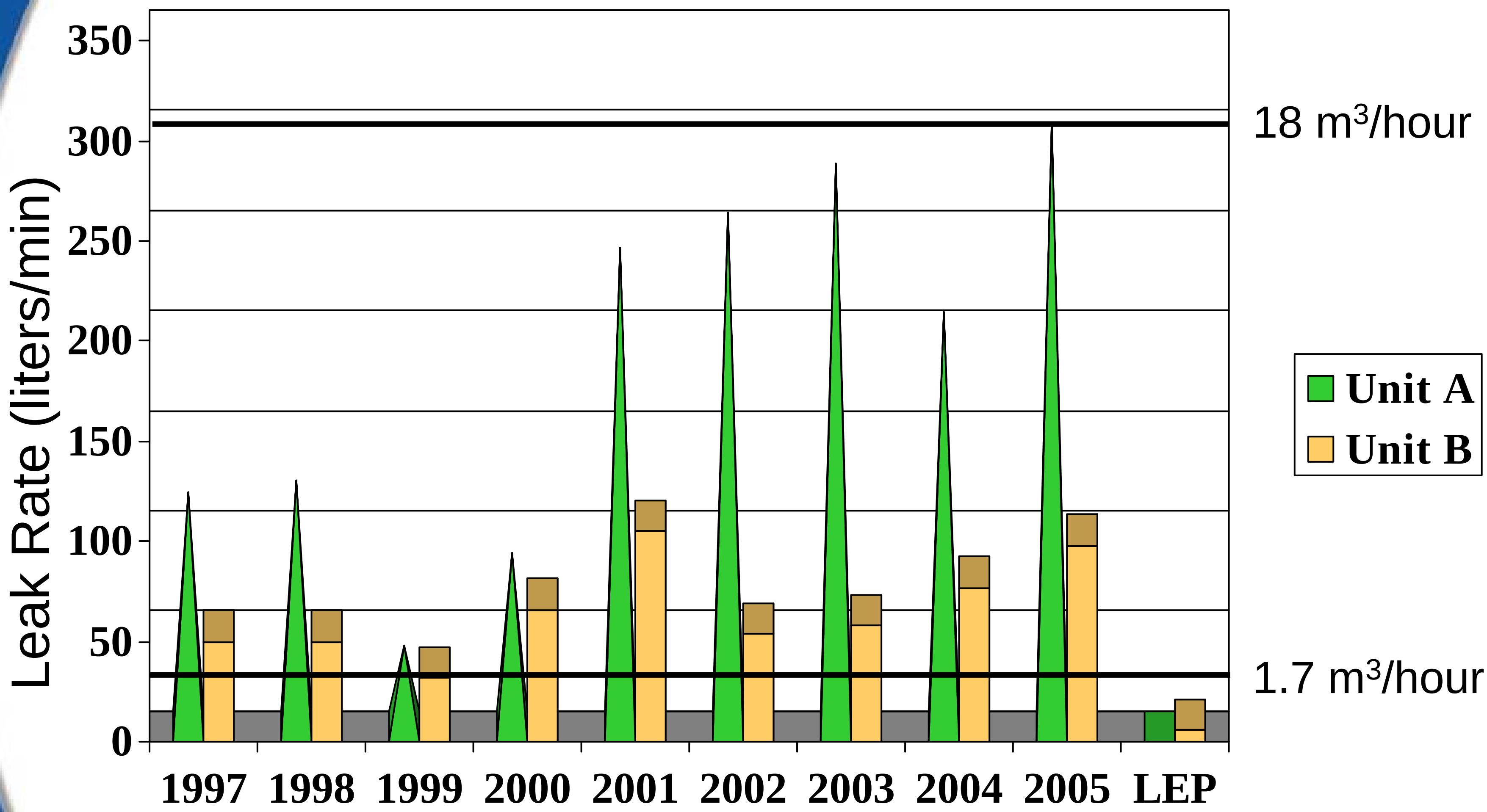
Reasons to Use LEP

- Upgrade is inexpensive
- Significant reduction of greenhouse gas are major benefit
- Refining, petrochemical and air separation plants have used this design for many years to minimize fugitive emissions

Industry Experience – Northern Natural Gas (U.S. Transmission Company)

- Monitored emission at two locations
  - Unit A leakage as high as 301 liters/minute (18 m^3/hour)
  - Unit B leakage as high as 105 liters/minute (6 m^3/hour)
- Installed Low Emission Packing (LEP)
  - Testing is still in progress
  - After 3 months, leak rate shows zero leakage increase

Northern Natural Gas - Leakage Rates



Northern Natural Gas Packing Leakage Economic Replacement Point

- Approximate packing replacement cost is $3,000 per compressor rod (parts/labor)
- Assuming gas at $7 per thousand cubic feet (Mcf) or $250/Mcm:
  - 50 liters/minute/1000 = 0.05 m3/minute
  - 0.05 x 60 minutes/hour= 3 m3/hour
  - 3 x 24 = 72 m3/day
  - 72 x 365 days/1000 = 26.3 Mcm/year
  - 26.3 x $250/Mcm = $6,600 per year leakage
  - This replacement pays back in <6 months

Reciprocating Compressor Lessons Learned

- A threshold exists when it is economic to replace rod packing in reciprocating compressors
- This threshold is often surpassed before replacement occurs
- Sharing these thresholds company-wide is an easy way for operators to determine when replacement is economic
- You must periodically measure emissions
- Economic replacement of rod packing reduces methane emissions, saves money

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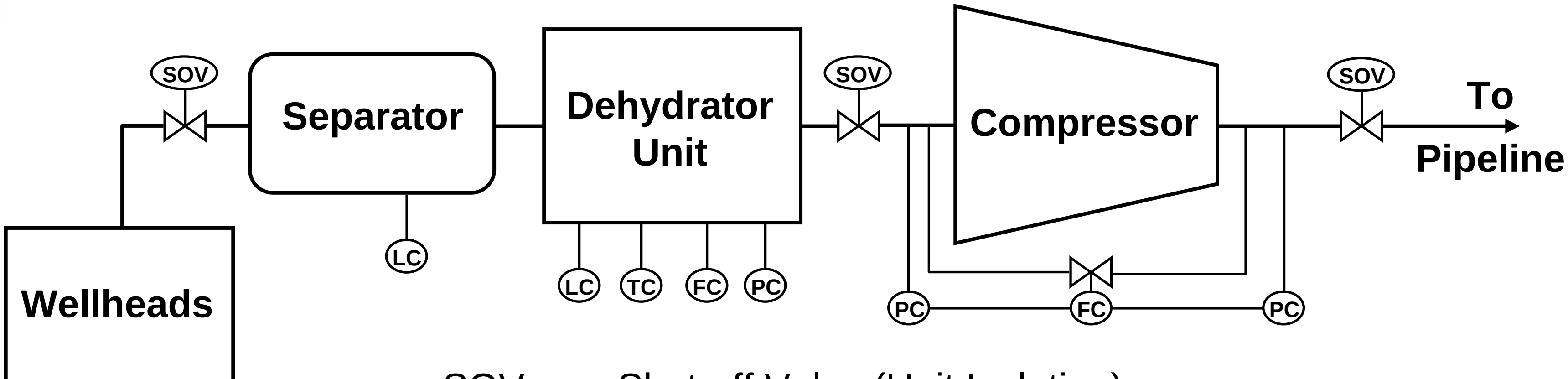
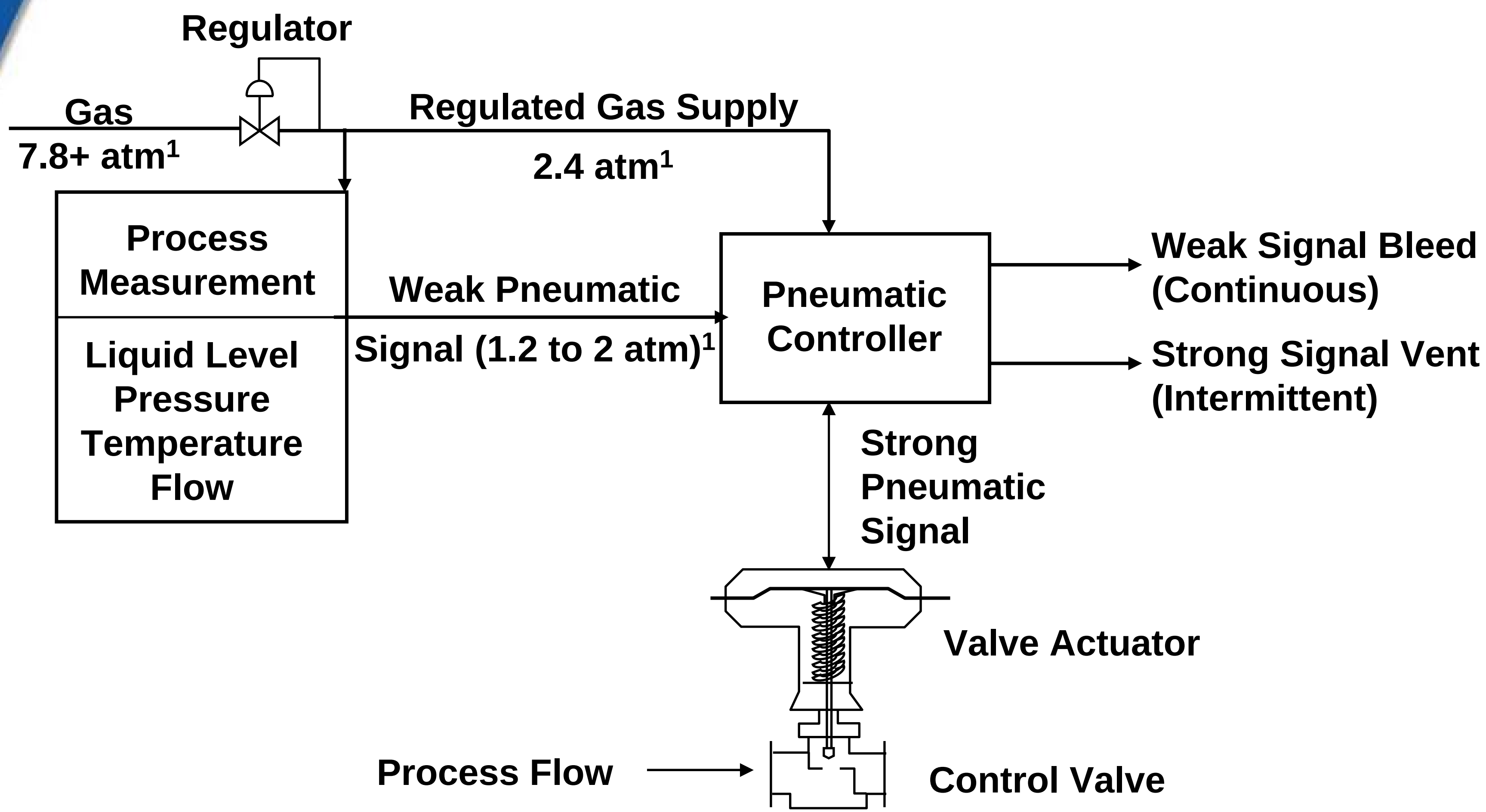
Methane Losses from Pneumatic Devices

- Pneumatic devices are used to actuate process controls on equipment throughout the natural gas industry



SOV	=	Shut-off Valve (Unit Isolation)
LC	=	Level Control (Separator, Contactor, Glycol Regenerator)
TC	=	Temperature Control (Regenerator Fuel Gas)
FC	=	Flow Control (Glycol Circulation, Compressor Bypass)
PC	=	Pressure Control (Flash Tank Pressure, Compressor Suction/Discharge)

How Gas Pneumatic Devices Work



[1] 1 atmosphere (atm) = 0 pounds per square inch gauge (psig) and 14.7 pounds per square inch atmospheric (psia)

1 atm = 1.013 bar and 101.3 kilopascals (kPa)

Pneumatic Devices: Methane Emissions

- As part of normal operations, pneumatic devices release natural gas to atmosphere
- High-bleed devices are defined as those that bleed in excess of 4 m^3 per day
  - Aggregates to more than 1,460 m^3/year
  - Typical high-bleed pneumatic devices bleed an average of 3,965 m^3/year
- Actual bleed rate is largely dependent on device's design and maintenance

Methane Recovery from Pneumatic Devices

- Option 1: Replace high-bleed devices with low-bleed devices
  - Replace at end of device's economic life
  - Typical cost range from $700 to $3000 per device
- Option 2: Retrofit controller with bleed reduction kits
  - Retrofit kit costs approximately $675
  - Payback time approximately 6 months
- Option 3: Maintenance aimed at reducing losses
  - Field survey of controllers
  - Re-evaluate the need for pneumatic positioners
  - Cost is low

- Field experience shows that up to 80% of all high-bleed devices can be replaced or retrofitted with low-bleed equipment

Five Steps for Reducing Methane Emissions from Pneumatic Devices

LOCATE and INVENTORY high-bleed devices

↓

ESTABLISH the technical feasibility and costs of alternatives

↓

ESTIMATE the savings

↓

EVALUATE economics of alternatives

↓

DEVELOP an implementation plan

Suggested Analysis for Replacement

- Replacing high-bleed controllers at end of economic life
  - Determine incremental cost of low-bleed device over high-bleed equivalent
  - Determine gas saved with low-bleed device using manufacturer specifications
  - Compare savings and cost
- Early replacement of high-bleed controllers
  - Compare gas savings of low-bleed device with full cost of replacement

Implementation[a]	Replace at End of Life	Early Replacements	
		Level Control	Pressure Control
Cost ($)	150 to 250[b]	513	1,809
Annual Gas Savings (m^3)	1,400 to 5,660	4,700	6,460
Annual Gas Savings (Mcf)	50 to 200	166	228
Annual Value of Saved Gas ($)[c]	350 to 1,400	1,165	1,596
IRR (%)	138 to 933	226	84
Payback (months)	2 to 9	6	14

[a] All data based on Partners' experiences and represented in U.S. economics
[b] Range of incremental costs of low-bleed over high bleed equipment
[c] Gas price is assumed to be $7/Mcf

Suggested Analysis for Retrofit

- Retrofit of low-bleed kit
  - Compare savings of low-bleed device with cost of conversion kit
  - Retrofitting reduces emissions by average of 90%

	Retrofit[a]
Implementation Costs[b]	$675
Bleed rate reduction (m^3/device/year)	6,200
Bleed rate reduction (Mcf/device/year)	219
Value of gas saved ($/year) [c]	$1,533
Payback (months)	6
Internal Rate of Return	226%

[a] On high-bleed controllers
[b] All data based on Partners' experiences and represented in U.S. economics.
[c] Gas price is assumed to be $7/Mcf

Methane to Markets

Suggested Analysis for Maintenance

- For maintenance aimed at reducing gas losses
  - Measure gas loss before and after procedure
  - Compare savings with labor (and parts) required for activity

	Reduce supply pressure	Repair & retune	Change settings	Remove valve positioners
Implementation Cost ($)[a]	207	31	0	0
Gas savings (m^3/year)	4,960	1,250	2,500	4,470
Gas savings (Mcf/year)	175	44	88	158
Value of gas saved ($/year)[b]	1,225	308	616	1,106
Payback (months)	3	2	<1	<1
IRR	592%	994%	--	--

[a] All data based on Partners' experiences and represented in U.S. economics
[b] Gas price is assumed to be $7/Mcf

Industry Experience: Marathon Oil (U.S. Production Company)

- Marathon surveyed 158 pneumatic devices at 50 production sites
- Half of the controllers were low-bleed
- High-bleed devices included
  - 35 of 67 level controllers
  - 5 of 76 pressure controllers
  - 1 of 15 temperature controllers

Marathon Oil: Industry Experience

- Marathon measured gas losses total 145 thousand m^3/year
- Level controllers account for 86% of losses
  - Losses averaged 0.2 m^3/hour/device
  - Losses ranged up to 1.4 m^3/hour/device (11.9 thousand m^3/year)
- Concluded that excessive losses can be heard or felt

Methane Savings at Compressor Stations: Discussion

- Industry experience applying these technologies and practices
- Limitations on application of these technologies and practices
- Actual costs and benefits