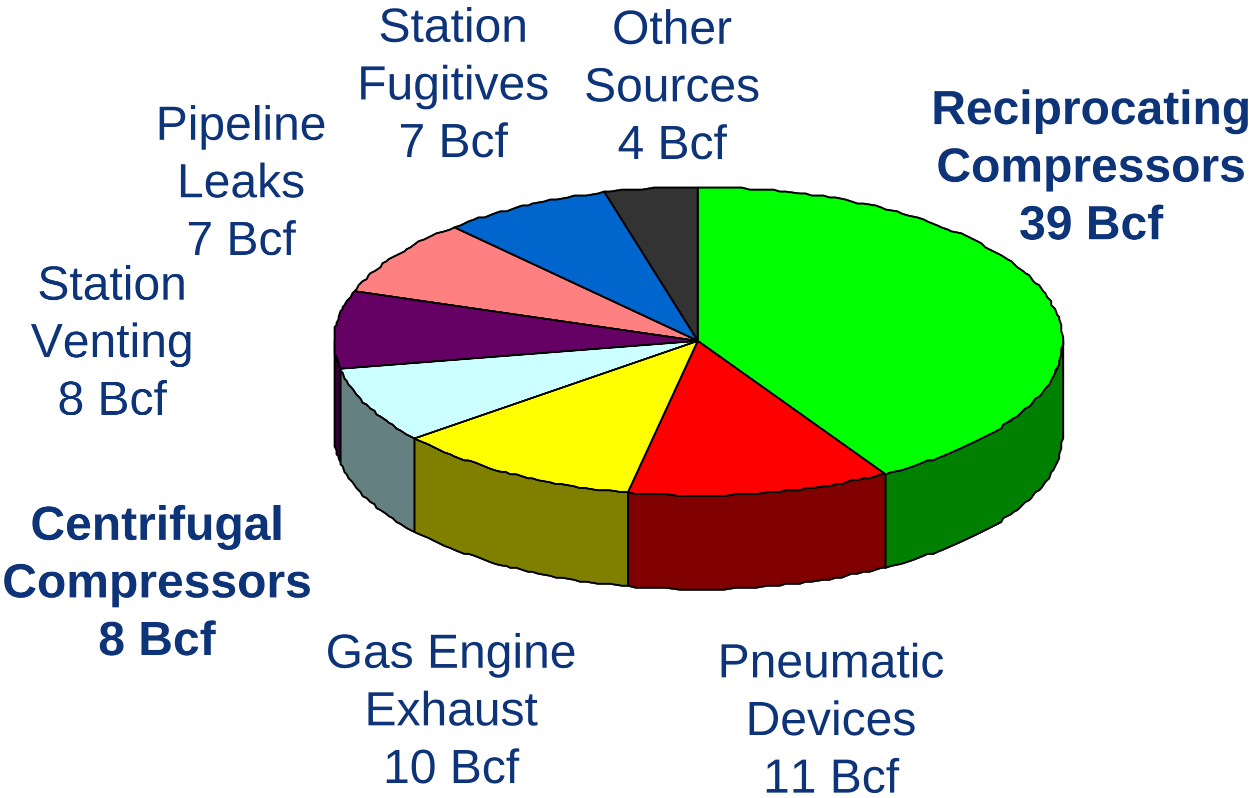
Methane Savings from Compressors

Lessons Learned from the
Natural Gas STAR Program

SGA Environmental Round Table
Charlotte, North Carolina
June 25 - 27, 2008

epa.gov/gasstar

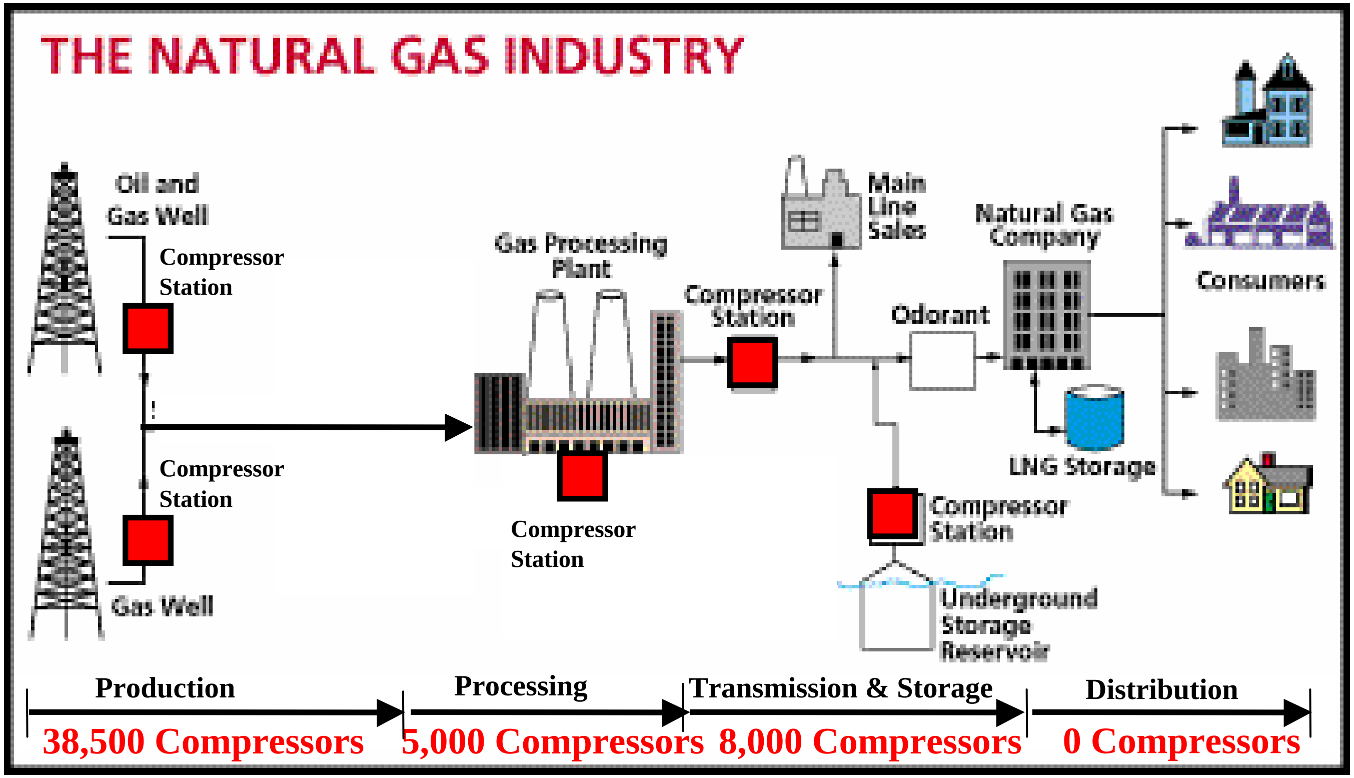
2006 Transmission Sector Methane Emissions



EPA. *Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990 – 2006.* April, 2008. Available on the web at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html
Natural Gas STAR reductions data shown as published in the inventory.

Compressor Methane Emissions What is the problem?

- Methane emissions from the ~51,500 compressors in the natural gas industry account for 89 Bcf/year or about 24% of all methane emissions from the natural gas industry

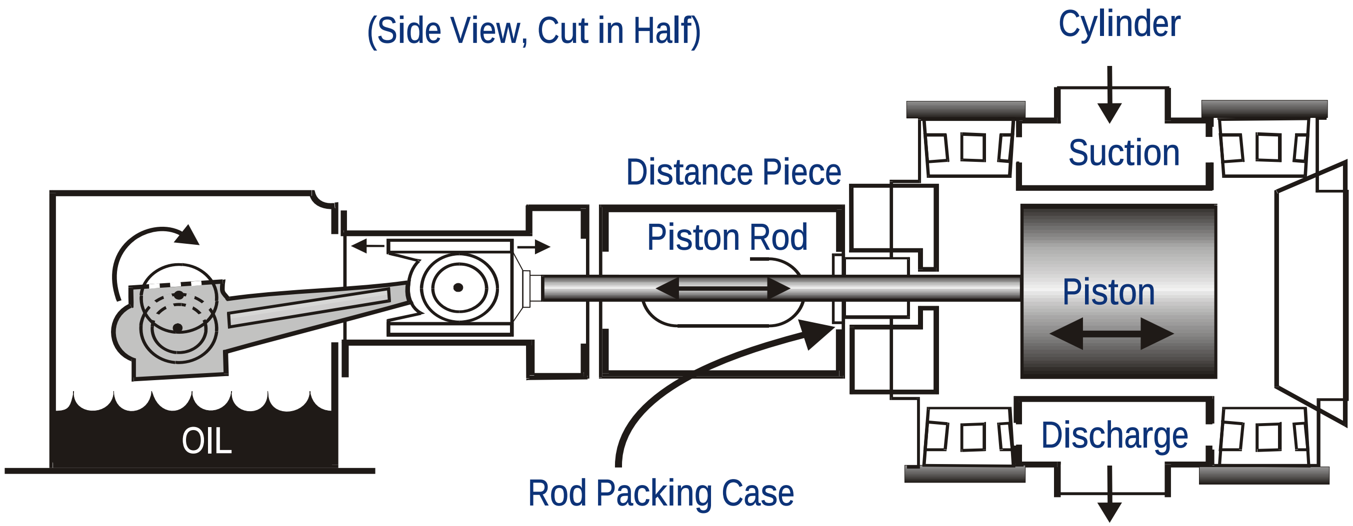


Methane Savings from Compressors: Agenda

- **Reciprocating Compressors**
  - **Methane Losses, Methane Savings, Industry Experience**
- Centrifugal Compressors
  - Methane Losses, Methane Savings, Industry Experience
- Reducing Emissions When Taking Compressors Offline
  - Methane Losses, Methane Savings, Industry Experience
- Discussion

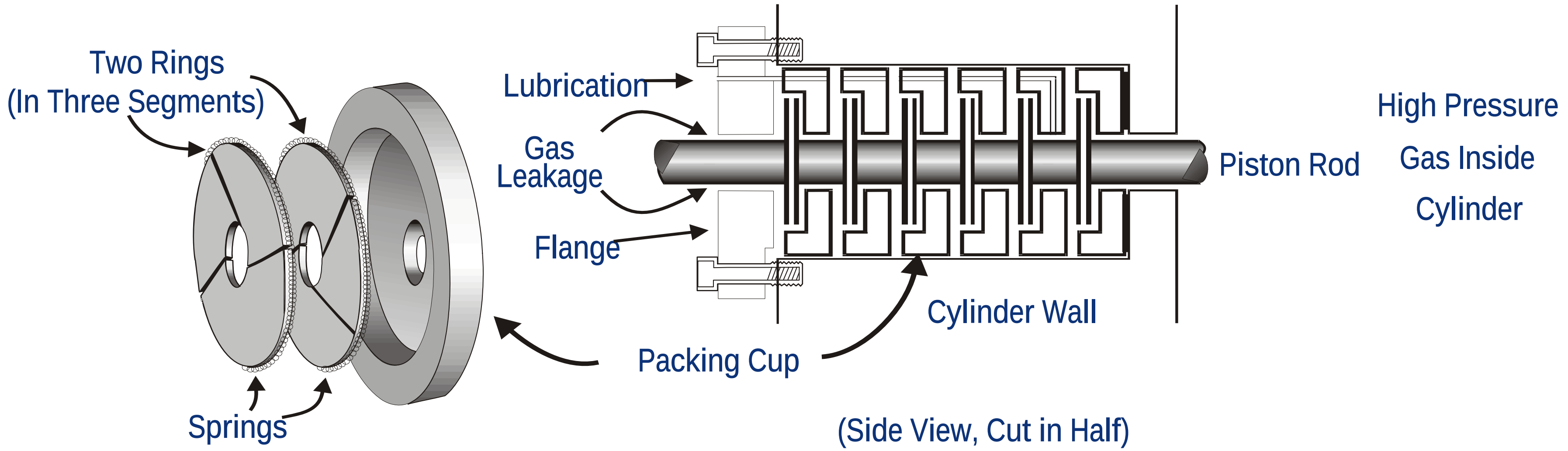
Methane Losses from Reciprocating Compressors

- Reciprocating compressor rod packing leaks some gas by design
  - Newly installed packing may leak 60 cubic feet per hour (cf/hour)
  - Worn packing has been reported to leak up to 900 cf/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 (no crush)
- Packing to rod (surface finish)
- Packing to cup (lapped surface)
- Packing to packing (dirt/lube)
- Cup to cup (out of tolerance)

What makes packing leak?

- Dirt or foreign matter (trash)
- Worn rod (.0015”/per inch dia.)
- Insufficient/too much lubrication
- Packing cup out of tolerance ($\leq$ 0.002”)
- 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	99	cf/hour-packing
Emission from Idle/Pressurized Compressor	145	cf/hour-packing
Leakage from Idle Compressor Packing Cup	79	cf/hour-packing
Leakage from Idle Compressor Distance Piece	34	cf/hour-packing

Leakage from Rod Packing on Running Compressors				
Packing Type	Bronze	Bronze/Steel	Bronze/Teflon	Teflon
Leak Rate (cf/hour)	70	63	150	24

Leakage from Rod Packing on Idle/Pressurized Compressors				
Packing Type	Bronze	Bronze/Steel	Bronze/Teflon	Teflon
Leak Rate (cf/hour)	70	N/A	147	22

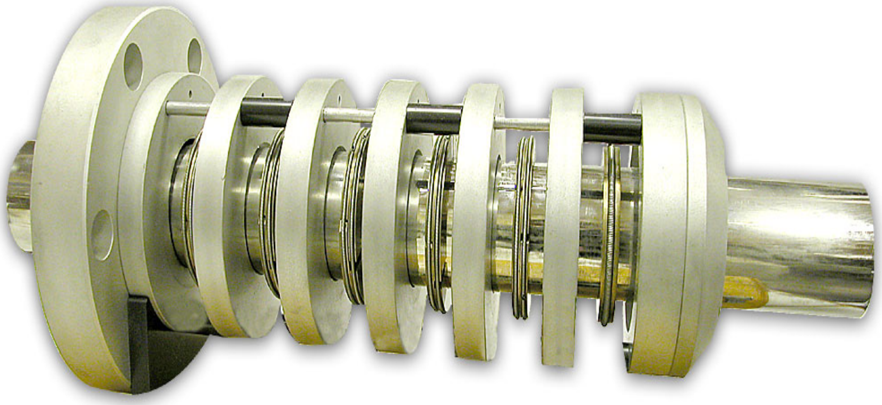
PRCI/ GRI/ EPA. *Cost Effective Leak Mitigation at Natural Gas Transmission Compressor Stations*

Steps to Determine Economic Replacement

- Measure rod packing leakage
  - When new packing installed – after worn-in
  - Periodically afterwards
- Determine cost of packing replacement
- Calculate economic leak reduction
- Replace packing when leak reduction expected will pay back cost

Cost of Rod Packing Replacement

- Assess costs of replacements
  - A set of rings: $ 135 to $ 1,080
    (with cups and case) $ 1,350 to $ 2,500
  - Rods: $ 2,430 to $13,500
    - Special coatings such as ceramic, tungsten carbide, or chromium can increase rod costs



Source: CECO

Calculate Economic Leak Reduction

- Determine economic replacement threshold
  - Partners can determine economic threshold for all replacements
  - This is a capital recovery economic calculation

Economic Replacement Threshold (cf/hour) =

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

Where:

CR = Cost of replacement ($)

DF = Discount factor at interest *i* =

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

H = Hours of compressor operation per year

GP = Gas price ($/thousand cubic feet)

Economic Replacement Threshold

- Example: Payback calculations for new rings and rod replacement

CR = \$1,620 for rings + \$9,450 for rod
= \$11,070
H = 8,000 hours per year
GP = \$7/Mcf

DF @ i = 10% and n = 1 year

$$DF = \frac{0.1(1+0.1)^1}{(1+0.1)^1 - 1} = \frac{0.1(1.1)}{1.1-1} = \frac{0.11}{0.1} = 1.1$$

DF @ i = 10% and n = 2 years

$$DF = \frac{0.1(1+0.1)^2}{(1+0.1)^2 - 1} = \frac{0.1(1.21)}{1.21-1} = \frac{0.121}{0.21} = 0.576$$

One year payback

$$ER = \frac{\$11{,}070 \times 1.1 \times 1{,}000}{(8{,}000 \times \$7)}$$

$$= 217 \text{ scf per hour}$$

Is Rod Packing Replacement Profitable?

- Replace packing when leak reduction expected will pay back cost
  - "leak reduction expected" is the difference between current leak rate and leak rate with new rings

Rings Only

Rings: $1,620
Rod: $0
Gas: $7/Mcf
Operating: 8,000 hours/year

Leak Reduction Expected (cf/hour)	Payback (months)
55	7
29	12
20	18
16	22

Rod and Rings

Rings: $1,620
Rod: $9,450
Gas: $7/Mcf
Operating: 8,000 hours/year

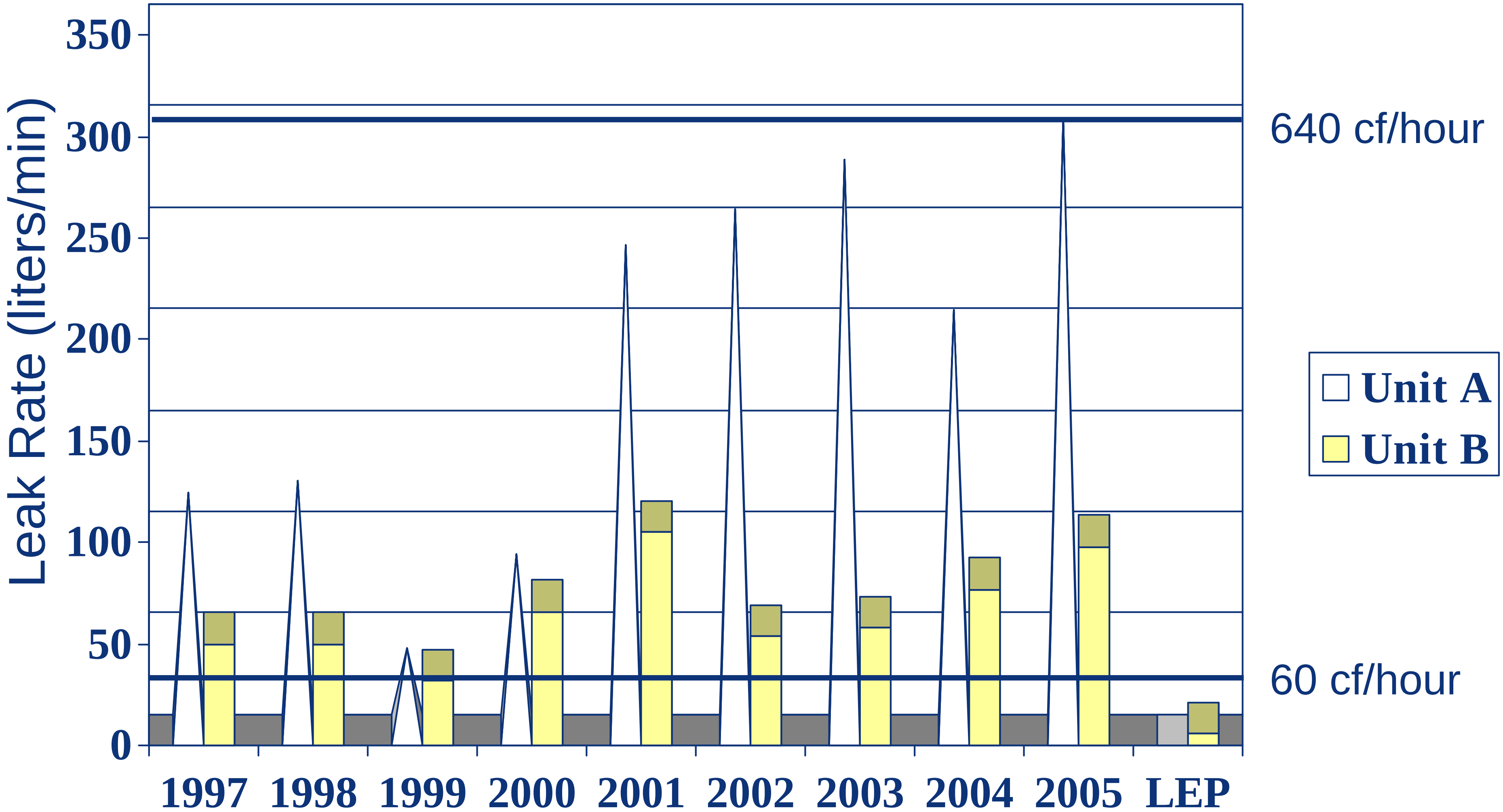
Leak Reduction Expected (cf/hour)	Payback (months)
376	7
197	13
137	18
108	22

Based on 10% interest rate
Mcf = thousand cubic feet

Industry Experience – Northern Natural Gas

- Monitored emission at two locations
  - Unit A leakage as high as 301 liters/min (640 cf/hour)
  - Unit B leakage as high as 105 liters/min (220 cf/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



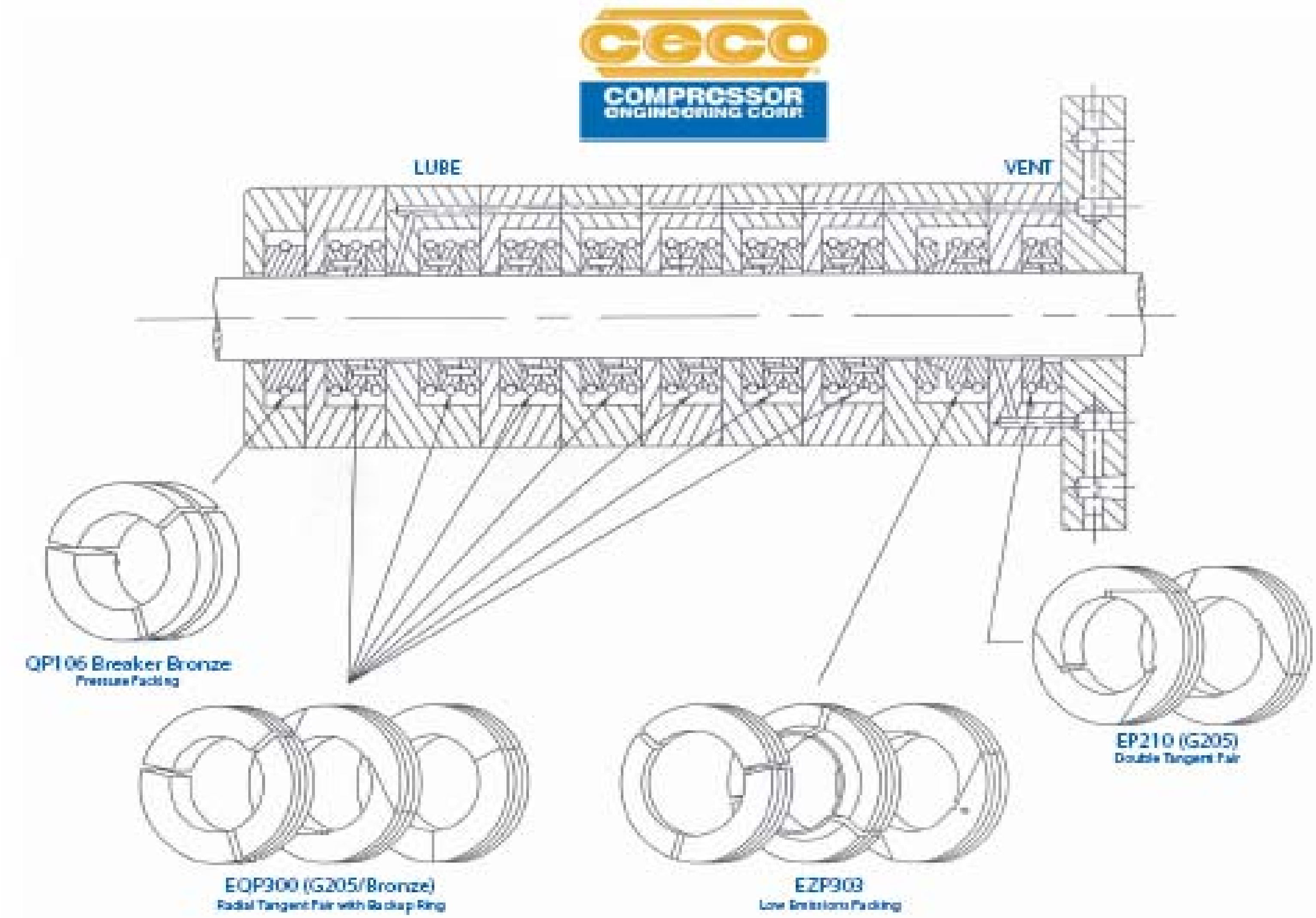
Northern Natural Gas Packing Leakage Economic Replacement Point

- Approximate packing replacement cost is $3,000 per compressor rod (parts/labor)
- Assuming gas at $7/Mcf:
  1 cubic foot/minute = 28.3 liters/minute
  - 50 liters/minute/28.316 = 1.8 scf/minute
  - 1.8 x 60 minutes/hour= 108 scf/hr
  - 108 x 24/1000 = 2.6 Mcf/day
  - 2.6 x 365 days= 950 Mcf/year
  - 950 x $7/Mcf = $6,650 per year leakage
  - This replacement pays back in <6 months

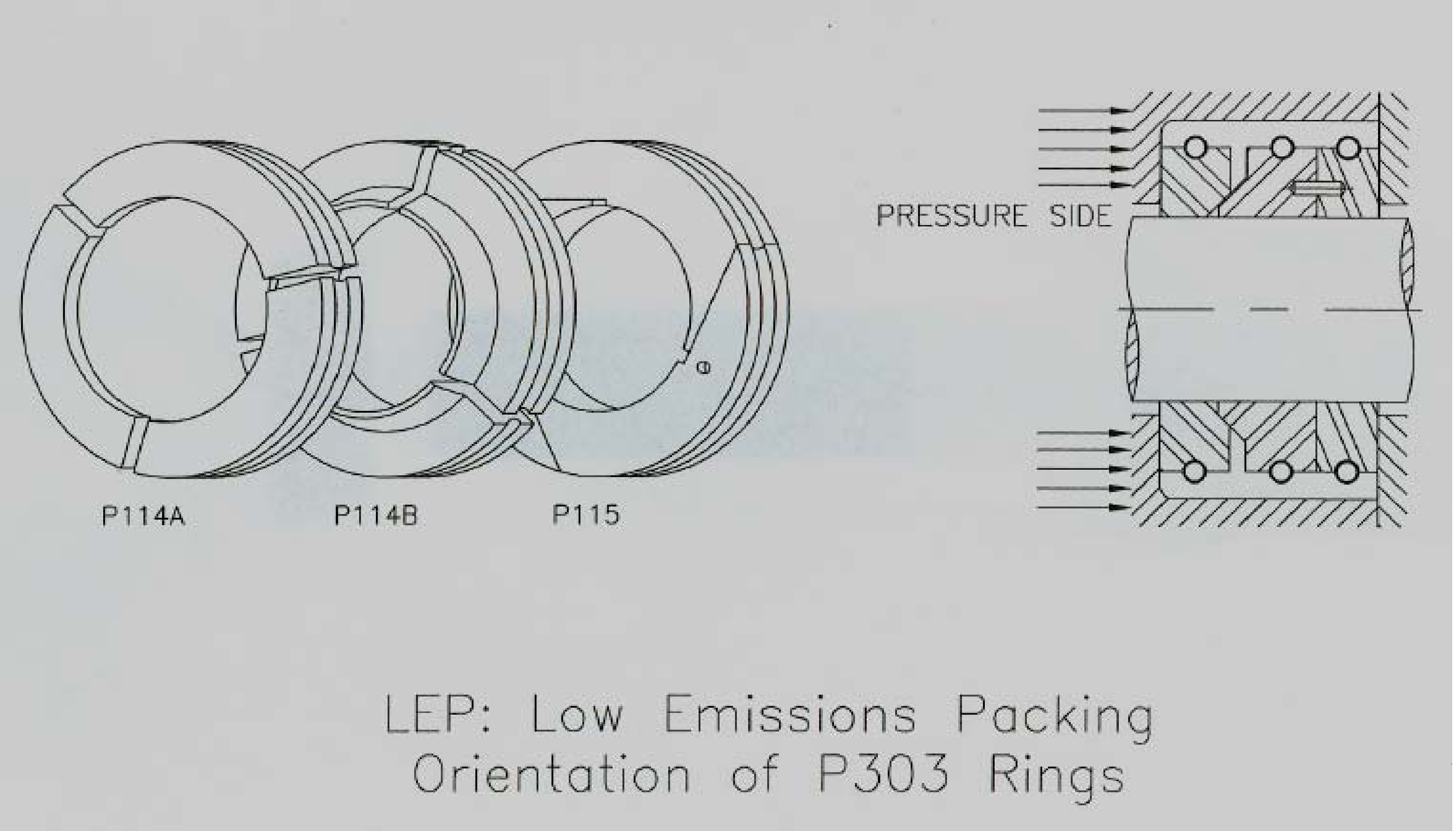
Low Emission Packing

- Low emission packing (LEP) overcomes low pressure to prevent leakage
- 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
- With gas at $7/Mcf, packing case leakage should be identified and fixed.

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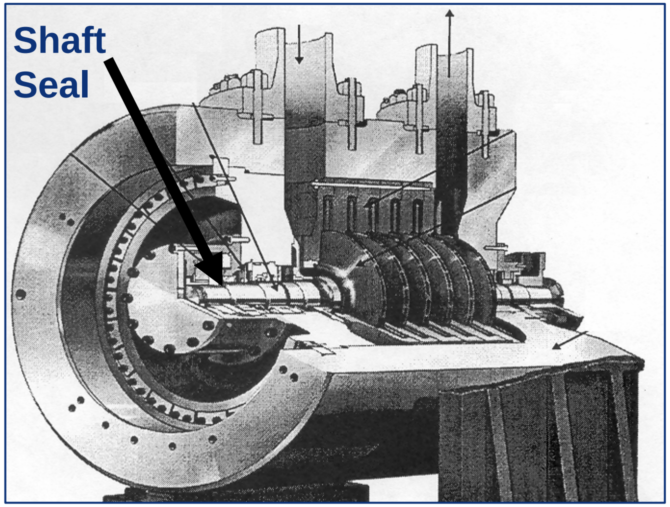
Methane Losses from Centrifugal Compressors

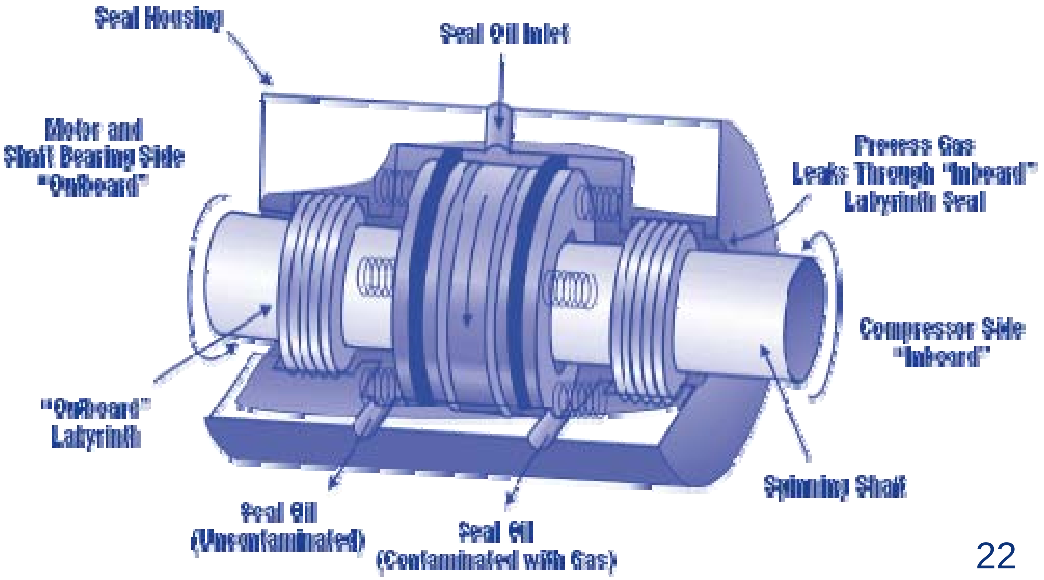
- Centrifugal compressor wet seals leak little gas at the seal face
  - Seal oil degassing may vent 40 to 200 cubic feet per **minute** (cf/minute) to the atmosphere
  - A Natural Gas STAR Partner reported wet seal emissions of 75 Mcf/day (52 cf/minute)



Centrifugal Compressor Wet Seals

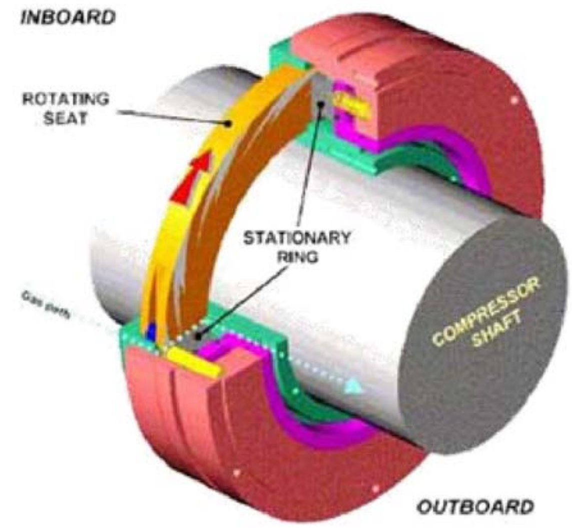
- High pressure seal oil circulates between rings around the compressor shaft
- Oil absorbs the gas on the inboard side
- Little gas leaks through the oil seal
- Seal oil degassing vents methane to the atmosphere

Source: PEMEX

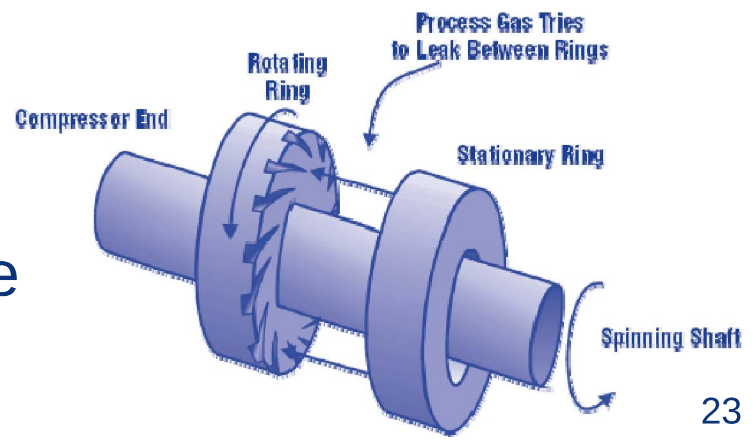


Natural Gas STAR Partners Reduce Emissions with Dry Seals

- Dry seal springs press the stationary ring in the seal housing against the rotating ring when the compressor is not rotating
- Sealing at high rotation speed pump gas between the seal rings creating a high pressure barrier to leakage
- Only a very small volume of gas escapes through the gap
- Two seals are often used in tandem
- Can operate for compressors up to 3,000 pounds per square inch gauge (psig) safely



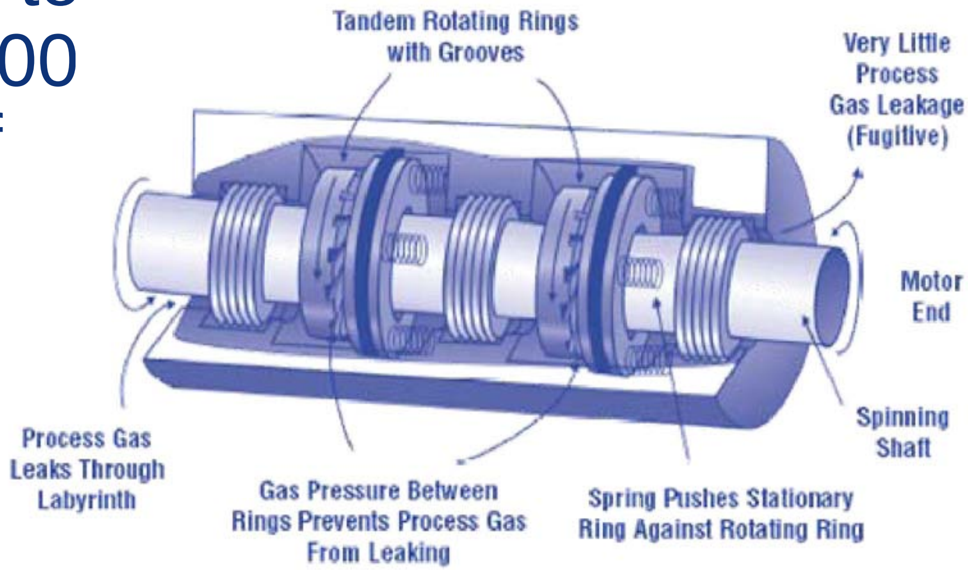
Source: PEMEX



Methane Savings through Dry Seals

- Dry seals typically leak 0.5 to 3 cf/minute
  - Significantly less than the 40 to 200 cf/minute emissions from wet seals
- Gas savings translate to approximately $112,000 to $651,000 at $7/Mcf

Source: PEMEX



Economics of Replacing Seals

- Compare costs and savings for a 6-inch shaft beam compressor

Cost Category	Dry Seal ($)	Wet Seal ($)
Implementation Costs[1]		
Seal costs (2 dry @ $13,500/shaft-inch, with testing)	$162,000	
Seal costs (2 wet @ $6,750/shaft-inch)		$81,000
Other costs (engineering, equipment installation)	$162,000	$0
Total implementation costs	$324,000	$81,000
Annual Operating and Maintenance	$14,100	$102,400
Annual Methane Emissions (@ $7/Mcf; 8,000 hours/year)		
2 dry seals at a total of 6 cf/minute	$20,160	
2 wet seals at a total of 100 cf/minute		$336,000
Total Costs Over 5-Year Period	$495,300	$2,273,000
Total Dry Seal Savings Over 5 Years		
Savings	$1,777,700	
Methane Emissions Reductions (Mcf; at 45,120 Mcf/year)	225,600	

[1] **Flowserve Corporation (updated costs and savings)**

Is Wet Seal Replacement Profitable?

- Replacing wet seals in a 6 inch shaft beam compressor operating 8,000 hours/year
  - Net present value = $1,337,769
    - Assuming a 10% discount over 5 years
  - Internal rate of return = 129%
  - Payback period = 10 months
    - Ranges from 3 to 11 months based on wet seal leakage rates between 40 and 200 cf/minute
- Economics are better for new installations
  - Vendors report that 90% of compressors sold to the natural gas industry are centrifugal with dry seals

Industry Experience – PEMEX

- PEMEX had 46 compressors with wet seals at its PGPB production site
- Converted three to dry seals
  - Cost $444,000/compressor
  - Saves 20,500 Mcf/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

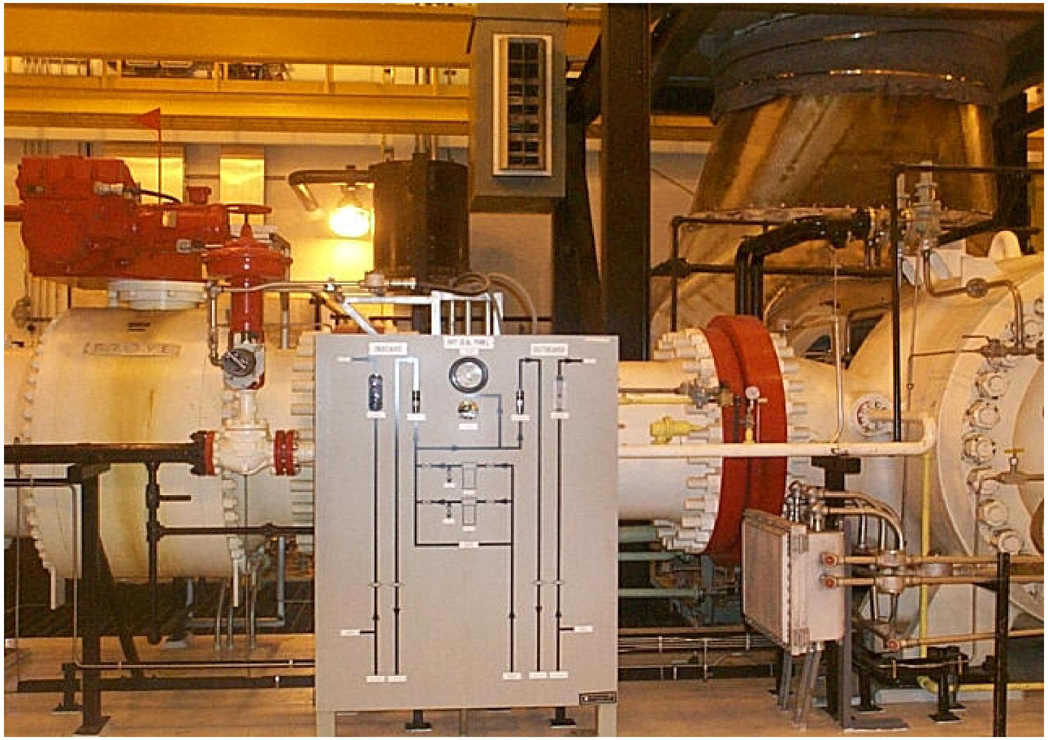
Finding More Opportunities

- Partners are identifying other technologies and practices to reduce emissions
  - BP-Indonesia degasses wet seal oil to low pressure fuel gas, capturing 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

TransCanada Experience: Gas-Gas Ejector

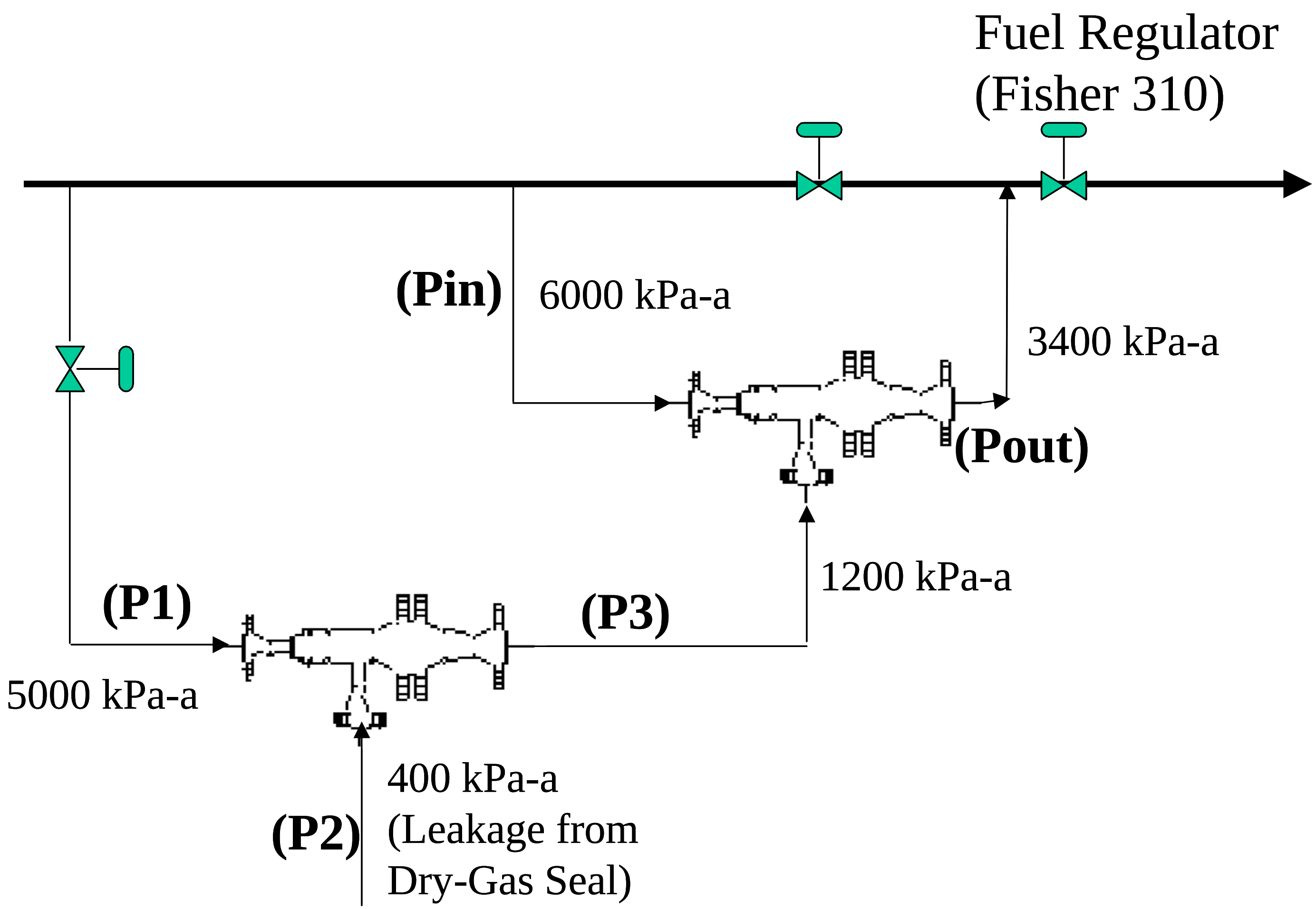
- Compressor Package Components
  Winchell Lk



Source: TransCanada

Dry seal panel, continuous gas venting by design

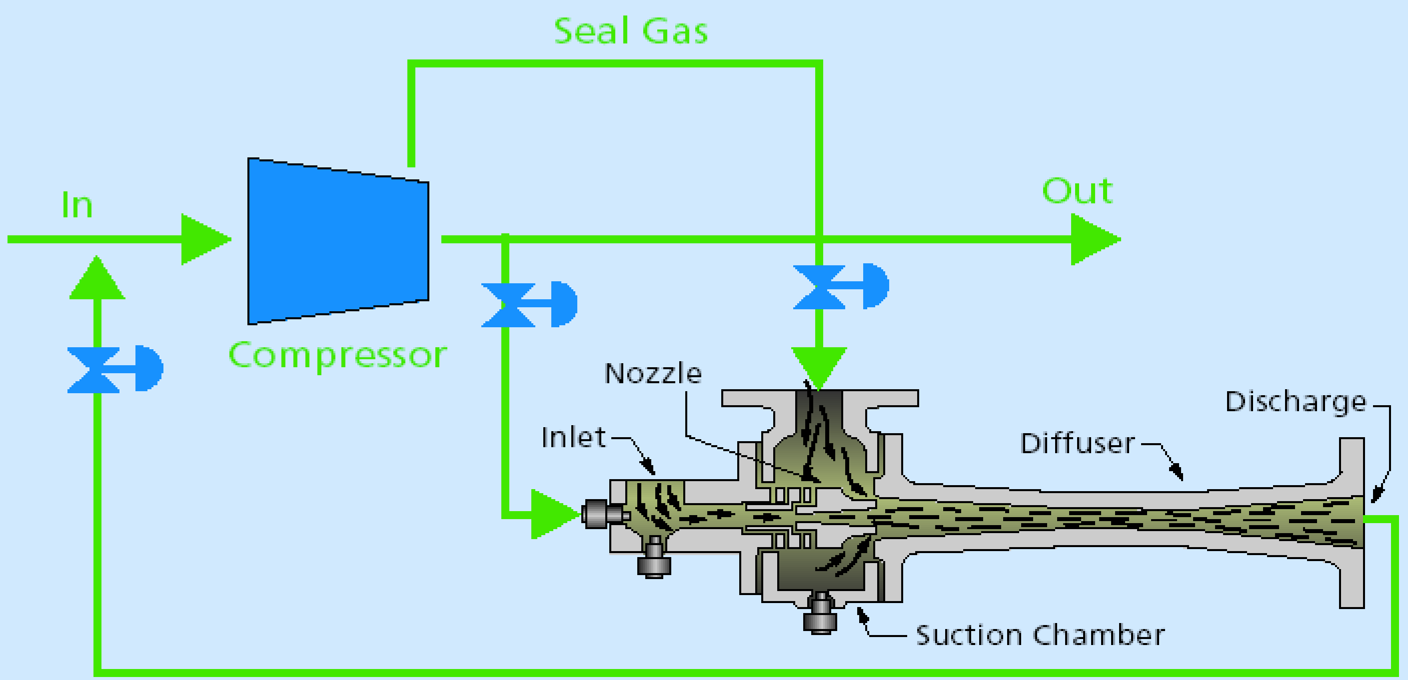
Supersonic Gas-Gas Ejector for Capturing Low Pressure Vent gases



Source: TransCanada

Gas-Gas Ejector for Dry Gas Seal Leak Capture

Conceptual Flow Diagram **US & Canadian patent filed**



Conceptual flow diagram for use of Ejector by TransCanada.
Ejector: Ludweg, EE, 1980.

Source: TransCanada

Supersonic Gas Injector

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

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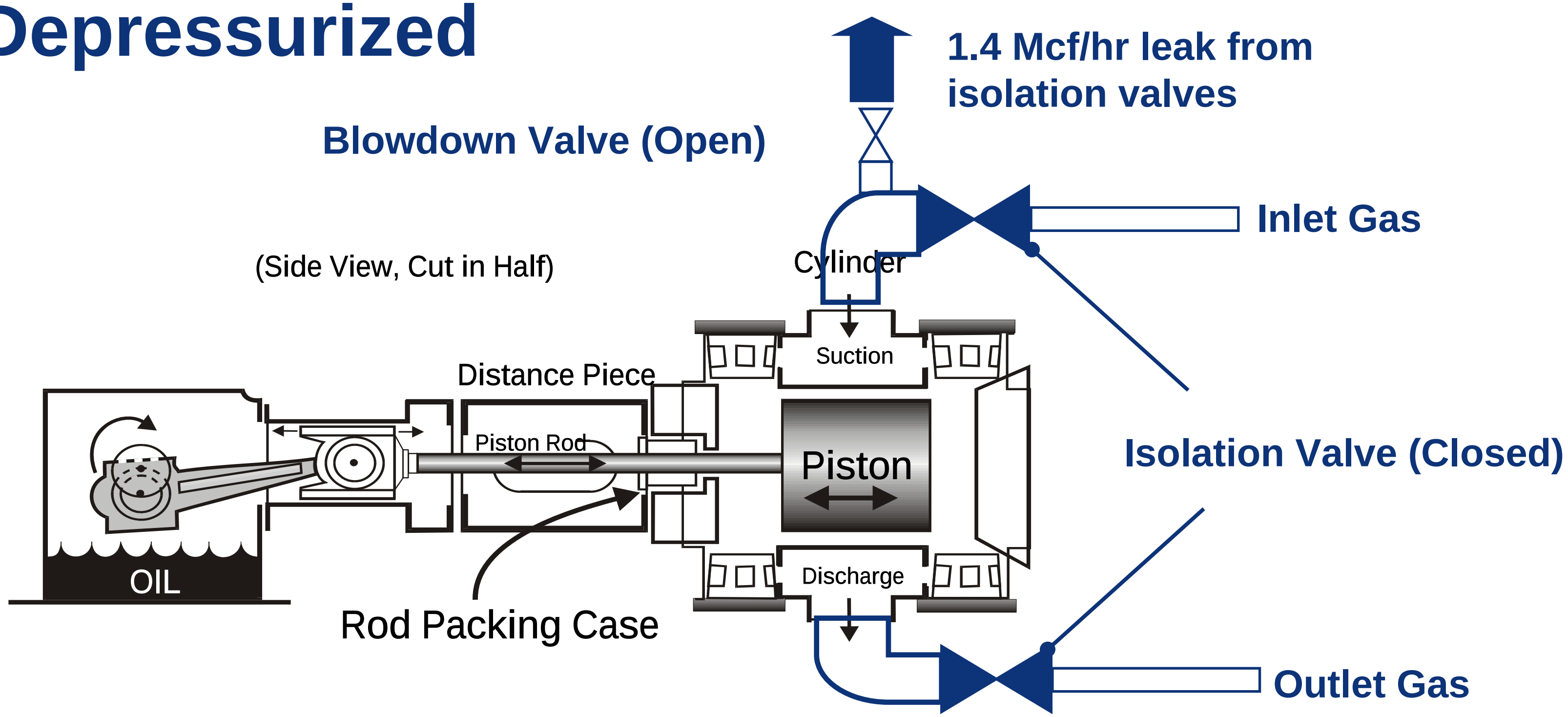
What is the Problem?

- 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 blowdown vents 15 Mcf gas to atmosphere on average
- Isolation valves
  - Leak about 1.4 Mcf/hr on average through open blowdown vents

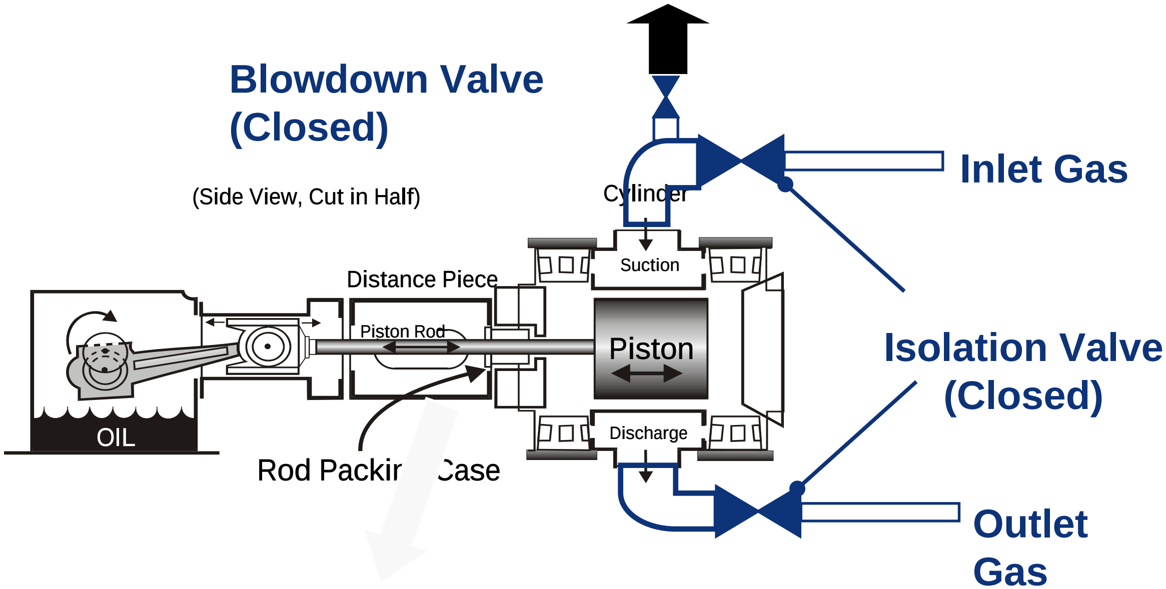
Basic Compressor Schematic

- Depressurized



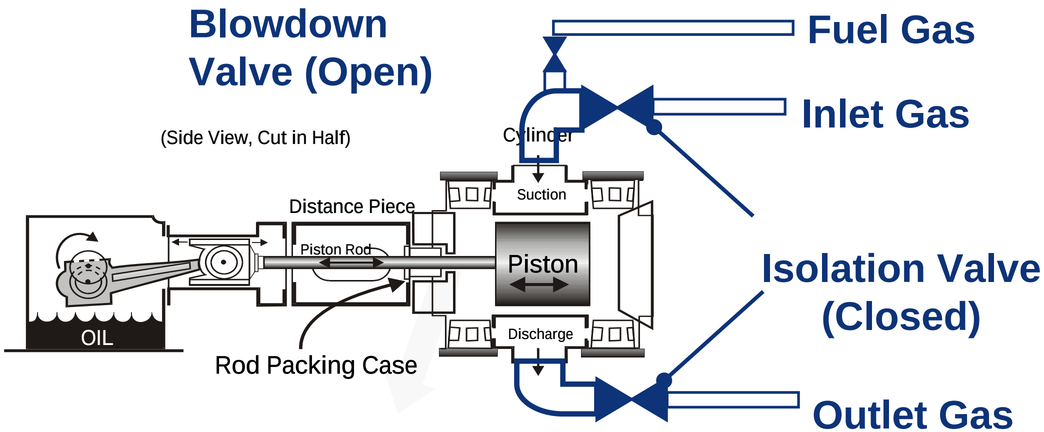
Methane Recovery - Option 1

- Keep off-line compressors pressurized
  - Requires no facility modifications
  - Eliminates methane vents
  - Seal leak higher by 0.30 Mcf/hr
  - Reduces fugitive methane losses by 0.95 Mcf/hr (68%)



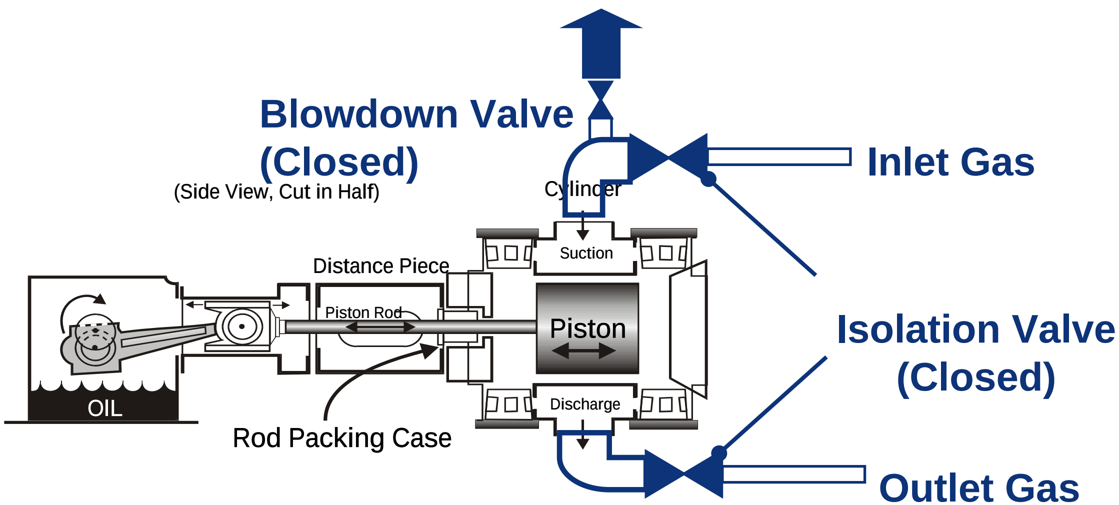
Methane Recovery - Option 2

- Route off-line compressor gas to fuel
  - Connect blowdown vent to fuel gas system
  - Off-line compressor equalizes to fuel gas pressure (100 to 150 pounds per square inch)
  - Eliminates methane vents
  - Seal leak higher by 0.125 Mcf/hr
  - Reduces fugitive methane losses by 1.275 Mcf/hr (91%)



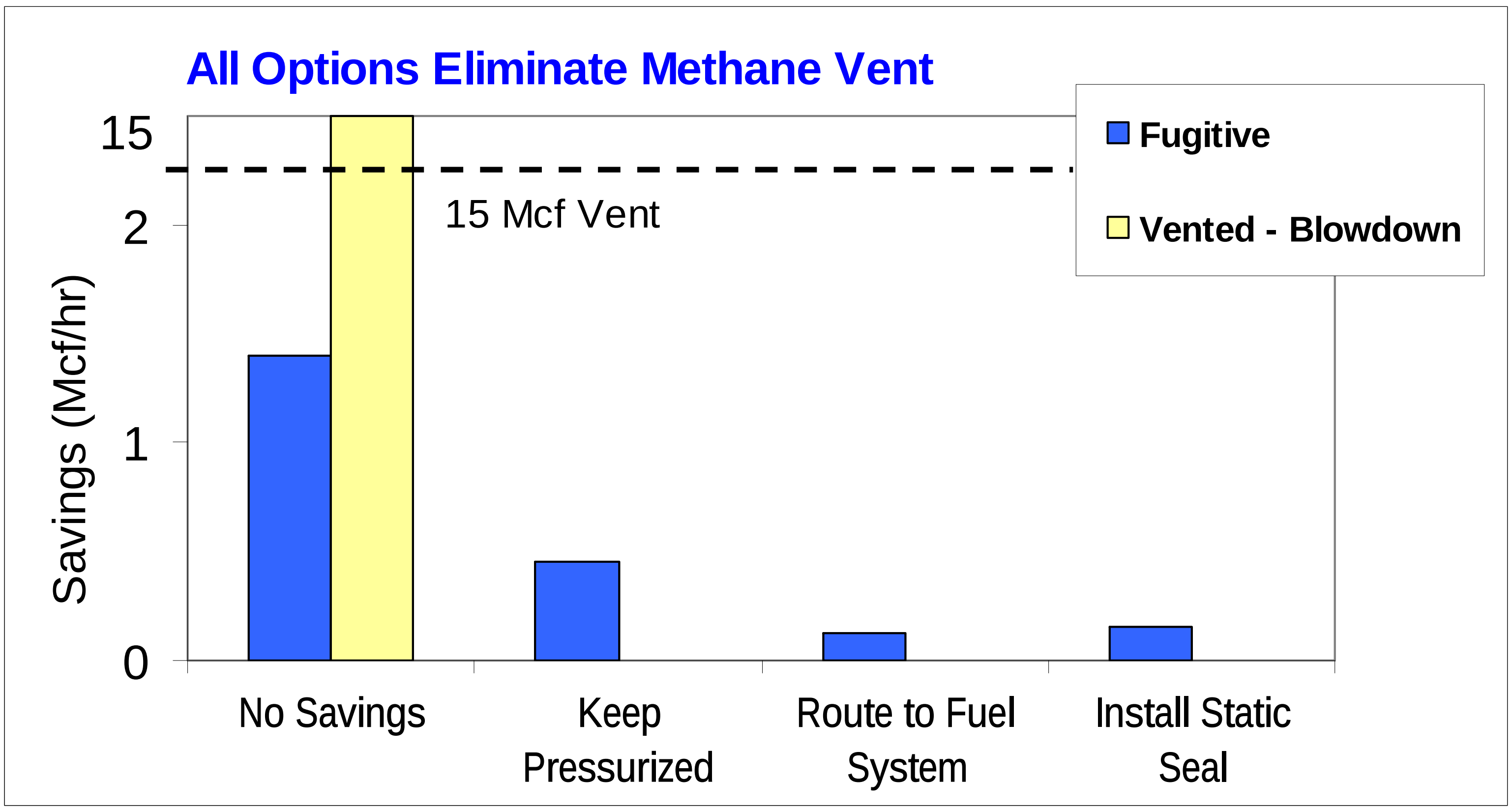
Methane Recovery - Option 3

- 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 1.25 Mcf/hr (89%)



Methane Recovery Options

- Methane savings comparison



Calculate Methane Emissions

- Blowdown losses = (# blowdowns) x (15 Mcf)[1]
- Fugitive losses = (# offline hours) x (1.4 Mcf/hr)[1]

- Total losses = blowdown + fugitive savings

- Example:
  - 2 blowdowns/yr x 15 Mcf
  - 1,752 offline hours x 1.4 Mcf/hr = 2,500 Mcf/yr

[1]EPA default values

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 $1,215 to $2,160 per compressor

Calculate Costs

- Option 3: Do not blow down and install static seal
  - Seals cost $675 per rod
  - Seal controller costs $1,350 per compressor
  - Less cost-effective in conjunction with Option 2

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	$ 1,688/compressor	$ 4,050/compressor
Off-line Leakage			
Baseload	225 Mcf/yr $ 1,575	63 Mcf/yr $ 441	75 Mcf/yr $ 525
Peak Load	1,800 Mcf/yr $ 12,600	500 Mcf/yr $ 3,500	600 Mcf/yr $ 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 $ 7.00/Mcf.			

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 (Mcf/yr)	520	4,400	+207	+1,345	+150	+1,200
Dollar Savings/yr[1]	$ 3,640	$ 30,800	$ 1,449	$ 9,415	$ 1,050	$ 8,400
Facilities Investment	0	0	$ 1,680	$ 1,680	$ 4,050	$ 4,050
Payback	Immediate	Immediate	1 yr	2 mons	4 yrs	6 mons
IRR[2]	>100%	>100%	82%	560%	9%	207%

[1] **Assuming value of gas is $7.00/Mcf.**

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

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

Discussion

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