2006 Transmission Sector Methane Emissions

- Reciprocating Compressors: 39 Bcf
- Station Fugitives: 7 Bcf
- Other Sources: 4 Bcf
- Pipeline Leaks: 7 Bcf
- Station Venting: 8 Bcf
- Centrifugal Compressors: 8 Bcf
- Gas Engine Exhaust: 10 Bcf
- Pneumatic Devices: 11 Bcf
- Other Sources: 4 Bcf
- Station Venting: 8 Bcf
- Centrifugal Compressors: 8 Bcf
- Gas Engine Exhaust: 10 Bcf
- Pneumatic Devices: 11 Bcf


Natural Gas STAR reductions data shown as published in the inventory.
Compressor Methane Emissions
What is the problem?

 Hawai 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.

![Compressor Methane Emissions Diagram](image)

**THE NATURAL GAS INDUSTRY**

- **Production**: 38,500 Compressors
- **Processing**: 5,000 Compressors
- **Transmission & Storage**: 8,000 Compressors
- **Distribution**: 0 Compressors
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

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission from Running Compressor</td>
<td>99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emission from Idle/Pressurized Compressor</td>
<td>145</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leakage from Idle Compressor Packing Cup</td>
<td>79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leakage from Idle Compressor Distance Piece</td>
<td>34</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Leakage from Rod Packing on Running Compressors

<table>
<thead>
<tr>
<th>Packing Type</th>
<th>Bronze</th>
<th>Bronze/Steel</th>
<th>Bronze/Teflon</th>
<th>Teflon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak Rate (cf/hour)</td>
<td>70</td>
<td>63</td>
<td>150</td>
<td>24</td>
</tr>
</tbody>
</table>

### Leakage from Rod Packing on Idle/Pressurized Compressors

<table>
<thead>
<tr>
<th>Packing Type</th>
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<th>Bronze/Steel</th>
<th>Bronze/Teflon</th>
<th>Teflon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak Rate (cf/hour)</td>
<td>70</td>
<td>N/A</td>
<td>147</td>
<td>22</td>
</tr>
</tbody>
</table>

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) = \( \frac{CR \times DF \times 1,000}{(H \times GP)} \)

Where:
- \( CR = \) Cost of replacement ($)
- \( DF = \) Discount factor at interest \( i = \)
- \( H = \) Hours of compressor operation per year
- \( GP = \) Gas price ($/thousand cubic feet)

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

<table>
<thead>
<tr>
<th>Rings Only</th>
<th>Rod and Rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rings:</td>
<td>$1,620</td>
</tr>
<tr>
<td>Rod:</td>
<td>$0</td>
</tr>
<tr>
<td>Gas:</td>
<td>$7/Mcf</td>
</tr>
<tr>
<td>Operating:</td>
<td>8,000 hours/year</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leak Reduction Expected (cf/hour)</th>
<th>Payback (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>7</td>
</tr>
<tr>
<td>29</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>16</td>
<td>22</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leak Reduction Expected (cf/hour)</th>
<th>Payback (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>376</td>
<td>7</td>
</tr>
<tr>
<td>197</td>
<td>13</td>
</tr>
<tr>
<td>137</td>
<td>18</td>
</tr>
<tr>
<td>108</td>
<td>22</td>
</tr>
</tbody>
</table>

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

Leak Rate (liters/min)

- Unit A
- Unit B

Leakage Rates from 1997 to 2005 for Units A and B. The highest leakage rate for Unit A is 640 cf/hour in 2005, and for Unit B, it is 60 cf/hour in 2001.
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

LEP: Low Emissions Packing
Orientation of P303 Rings
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.
Methane Savings from Compressors: Agenda

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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 pumps 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

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

<sup>1</sup> 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

Fuel Regulator
(Fisher 310)

(Pin) 6000 kPa-a

(P1) 5000 kPa-a

(P2) 400 kPa-a
(Leakage from Dry-Gas Seal)

(P3) 1200 kPa-a

(Pout) 3400 kPa-a

Source: TransCanada
Gas-Gas Ejector for Dry Gas Seal Leak Capture

Conceptual Flow Diagram

Seal Gas

In

Compressor

Nozzle

Inlet

Diffuser

Discharge

Suction Chamber

Out

Source: TransCanada

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
Methane Savings from Compressors: Agenda

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- Discussion
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

1.4 Mcf/hr leak from isolation valves

Blowdown Valve (Open)
(Side View, Cut in Half)

Inlet Gas

Isolation Valve (Closed)

Outlet Gas

Cylinder

Suction

Discharge

Piston

Distance Piece

Piston Rod

Rod Packing Case

OIL

Inlet Gas

Outlet Gas
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

- No Savings
- Keep Pressurized
- Route to Fuel System
- Install Static Seal

All Options Eliminate Methane Vent

Savings (Mcf/hr)

- 15 Mcf Vent

Fugitive
Vented - Blowdown
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

<table>
<thead>
<tr>
<th></th>
<th>Option 1</th>
<th>Option 2</th>
<th>Option 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Keep Pressurized</td>
<td>Keep Pressurized and Tie to Fuel Gas</td>
<td>Keep Pressurized and Install Static Seal</td>
</tr>
<tr>
<td><strong>Capital</strong></td>
<td>None</td>
<td>$ 1,688/compressor</td>
<td>$ 4,050/compressor</td>
</tr>
<tr>
<td><strong>Off-line Leakage</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseload</td>
<td>225 Mcf/yr</td>
<td>63 Mcf/yr</td>
<td>75 Mcf/yr</td>
</tr>
<tr>
<td></td>
<td>$ 1,575</td>
<td>$ 441</td>
<td>$ 525</td>
</tr>
<tr>
<td>Peak Load</td>
<td>1,800 Mcf/yr</td>
<td>500 Mcf/yr</td>
<td>600 Mcf/yr</td>
</tr>
<tr>
<td></td>
<td>$ 12,600</td>
<td>$ 3,500</td>
<td>$ 4,200</td>
</tr>
</tbody>
</table>

*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

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<tr>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base</td>
<td>Peak</td>
<td>Base</td>
<td>Peak</td>
<td>Base</td>
<td>Peak</td>
</tr>
<tr>
<td>Net Gas Savings (Mcf/yr)</td>
<td>520</td>
<td>4,400</td>
<td>+207</td>
<td>+1,345</td>
<td>+150</td>
<td>+1,200</td>
</tr>
<tr>
<td>Dollar Savings/yr(^1)</td>
<td>$ 3,640</td>
<td>$ 30,800</td>
<td>$ 1,449</td>
<td>$ 9,415</td>
<td>$ 1,050</td>
<td>$ 8,400</td>
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<tr>
<td>Facilities Investment</td>
<td>0</td>
<td>0</td>
<td>$ 1,680</td>
<td>$ 1,680</td>
<td>$ 4,050</td>
<td>$ 4,050</td>
</tr>
<tr>
<td>Payback</td>
<td>Immediate</td>
<td>Immediate</td>
<td>1 yr</td>
<td>2 mons</td>
<td>4 yrs</td>
<td>6 mons</td>
</tr>
<tr>
<td>IRR(^2)</td>
<td>&gt;100%</td>
<td>&gt;100%</td>
<td>82%</td>
<td>560%</td>
<td>9%</td>
<td>207%</td>
</tr>
</tbody>
</table>

\(^1\) 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