Directed Inspection & Maintenance (DI&M) and Compressor Best Practices

Ministerio de Minas y Energía
Ministerio de Ambiente, Vivienda y Desarrollo Territorial
Occidental Oil & Gas Corporation and Environmental Protection Agency, USA

October 6, 2005
DI&M and Compressor Practices: Agenda

• Directed Inspection and Maintenance (DI&M)
  – David Picard, Clearstone Engineering
• DI&M with Optical Imaging
  – Don Robinson, ICF Consulting
• Compressor Best Practices
  – Don Robinson, ICF Consulting
Directed Inspection and Maintenance (DI&M)

Agenda
- Leak Characteristics
- Leak Trends
- Key Principles
- Important Benefits
- Conclusion
Leak Characteristics

- Contribute significantly to total VOC and GHG emissions at upstream oil and gas facilities
- Only a few percent of the components at a site actually leak
- Most of the leakage is usually from just a few big leakers.
- Big leakers often go unnoticed because they occur in difficult-to-access, low-traffic, crowded or noisy areas, or the amount of leakage is not fully appreciated
- Big leakers may also occur because of severe/demanding applications coupled with high cost or difficulty of repairs
- Leakage is mostly from components in gas/vapor service
## Fugitive Equipment Leaks

<table>
<thead>
<tr>
<th>Facility Type</th>
<th>Number of Components surveyed Per Site</th>
<th>Leak Frequency (%)</th>
<th>Emissions From All Leaking Sources</th>
<th>Combustion to THC Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Methane (tonnes/year)</td>
<td>Value ($/year)</td>
</tr>
<tr>
<td>Gas Plants</td>
<td></td>
<td></td>
<td>1.7</td>
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<tr>
<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>16050</td>
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<td>3.5</td>
<td>471</td>
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<td>3672</td>
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<td>10.3</td>
<td>2334</td>
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<td>TOTAL</td>
<td>148920</td>
<td></td>
<td></td>
<td>8320</td>
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<tr>
<td>AVERAGE</td>
<td>16547</td>
<td></td>
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<tr>
<td>Gas Plants</td>
<td></td>
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<td>Compressor Stations</td>
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<td>5.1</td>
<td>110</td>
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<tr>
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<td>4626</td>
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<td>1.1</td>
<td>96</td>
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<td></td>
<td>3084</td>
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<td>0.7</td>
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<td>6168</td>
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<td>1568</td>
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<td></td>
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<td>4</td>
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<td>2115</td>
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<td>2516</td>
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<td>TOTAL</td>
<td>22300</td>
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<td>767</td>
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<td>AVERAGE</td>
<td>2478</td>
<td></td>
<td>1.5</td>
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<td>Well Sites</td>
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<td></td>
<td>1617</td>
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<tr>
<td></td>
<td>1797</td>
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<td>0.4</td>
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<tr>
<td>TOTAL</td>
<td>4888</td>
<td></td>
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<tr>
<td>AVERAGE</td>
<td>407</td>
<td></td>
<td>0.7</td>
<td>0</td>
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</tbody>
</table>

Value of emissions based on natural gas price of $6.78/GJ
## Residual Flaring

<table>
<thead>
<tr>
<th>Facility</th>
<th>Residual THC Flaring Rate (10^3 m^3/day)</th>
<th>THC Emissions (10^3 m^3/year)</th>
<th>Methane Emissions (10^3 m^3/year)</th>
<th>GHG Emission tonnes CO₂E/year</th>
<th>Value of Flared Gas ($/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Plant #1</td>
<td>0.56</td>
<td>4</td>
<td>3</td>
<td>540</td>
<td>53,765</td>
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<tr>
<td>Gas Plant #2</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Gas Plant #3</td>
<td>5.28</td>
<td>39</td>
<td>28</td>
<td>5,136</td>
<td>227,445</td>
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<tr>
<td>Gas Plant #4</td>
<td>3.43</td>
<td>29</td>
<td>18</td>
<td>3,336</td>
<td>342,272</td>
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<tr>
<td>Gas Plant #5</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Gas Plant #6</td>
<td>2.83</td>
<td>21</td>
<td>14</td>
<td>5,590</td>
<td>219,000</td>
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<td>Gas Plant #7</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>Gas Plant #8</td>
<td>10.99</td>
<td>80</td>
<td>66</td>
<td>10,266</td>
<td>1,249,588</td>
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<tr>
<td>Gas Plant #9</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
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<tr>
<td>TOTAL</td>
<td>23.09</td>
<td>172</td>
<td>130</td>
<td>24,868</td>
<td>2,092,070</td>
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<tr>
<td>AVERAGE</td>
<td>2.57</td>
<td>19</td>
<td>14</td>
<td>2,763</td>
<td>232,452</td>
</tr>
</tbody>
</table>

Value of emissions based on natural gas price of $6.78/GJ

NA – Excessive flaring was not observed at this facility
Noteworthy Leak Trends

• Most likely sources of big leaks:
  – Compressor seals
  – Open-ended lines and blowdown systems
  – Pressure relief valves
  – Pressure-vacuum safety valves
  – Tank hatches

• Least likely sources of big leaks:
  – Valve stem packing systems
  – Connectors

• Components in odorized or H$_2$S service leak less than those in non-odorized or non-toxic service

• Components in thermal cycling, vibration or cryogenic service have increased leakage
Key Principles of DI&M

• Minimize the potential for big leakers and provide early detection and repair of these when they occur.

• Focus efforts on the areas most likely to offer significant cost-effective control opportunities, with coarse or less frequent screening of other areas.

• Implement repairs as soon as possible, or at the next facility turnaround if a major shutdown is required.

• Consider leakage directly to the atmosphere as well as into vent, flare, drain and blowdown systems.
Important Benefits of DI&M

• Attractive payback (often <6 months)
• Reduced maintenance costs
• Reduced downtime
• Improved process efficiency
• Safer work environment
• Cleaner environment
• Resource conservation
• Lower methane emissions
Useful Tools

• Leak Detection
  – Bubble Tests
  – Handheld Vapor Sensors
  – Ultrasonic Leak Detectors
  – IR Cameras

• Leak Quantification
  – Bagging
  – Hi-Flow Sampler
  – Tracer Tests
  – Velocity Probes
  – Total Capture and Flow Measurement
  – Remote Sensing (e.g., DIAL)
Conclusions

• DI&M is a rational approach to managing fugitive emissions.
  – **Effective means of achieving significant cost-effective reductions in methane emissions.**
  – **An environmentally responsible choice.**

• A BMP for conducting DI&M at production facilities is currently being developed in Canada (CAPP, SEPAC, EC and EUB) and is expected to become a regulatory requirement (End of 2005).

• A multi-years study for US EPA/GRI/KSU will also be producing additional data for the Natural Gas STAR DI&M BMP (Fall 2005)
DI&M with Optical Imaging

Agenda

• DI&M by Leak Imaging
• Imaging Technology
• Imaging Video
DI&M by Leak Imaging

• Real-time visual image of gas leaks
  – Quicker identification & repair of leaks
  – Screen hundreds of components an hour
  – Screen inaccessible areas simply by viewing them
Technologies for Methane Detection

• Two technologies currently in development
• Backscatter Absorption Gas Imaging (BAGI)
  – Viewing area illuminated with IR laser light
  – IR camera images reflected laser light
  – Gas cloud absorbs the IR light (negative image)
• Passive IR Imaging
  – IR camera acquires image in full light spectrum
  – Optics separate IR frequency characteristic to chemical leak
  – Camera images equipment at selected IR frequency where
    light absorption by gas cloud provides a visual image
IR BAGI Camera

- Developed by Sandia National Laboratory
- Real-time instantaneous detection
- No quantification of detected leaks yet
- Does not differentiate chemical species
  - Tuned to optimum wavelength absorbed by chemical species
Backscatter Absorption Gas Imaging (BAGI) Process

- Incident IR laser light reflects off background & returns to camera
- IR camera creates black & white image of equipment
- Chemical plume absorbs IR light creating a negative image
- Leak plume appears as a black, smoky image in BAGI camera

Source: As Adapted from McRae, Tom, *GasVue: A Rapid Leak Location Technology for Large VOC Fugitive Emissions.* (Presentation at the CSI Petroleum Refining Sector Equipment Leaks Group, Washington, DC, Sept. 9, 1997).

Note: Although this Exhibit shows the gas in contact with the background material, it is not a requirement that the gas be in contact with the background. The gas plume need only be between the background and the infrared camera.
IR BAGI Camera, cont.

• **Portable**
  – Camera ~20 pounds
  – Shoulder- or tripod-mounted operation
  – Size of a shoulder-mounted TV camera

• **DC or AC Power**
  – Rechargeable battery back-pack ~12 pounds

• **Camera viewer and tape recording toggle between IR and visible light**
Leak Detected w/BAGI Camera

Visible light view of leaking flange

Infrared view of leaking flange

Leaking flange

Flange

Hydrocarbon plume
LSI Hawk Camera

- Does not quantify leaks
- Battery operated
- Also operated from helicopter to survey cross country pipelines
- Images pipeline leaks from 2 miles distance
Infrared Gas Imaging Video

- Recording of fugitive leak found by infrared camera
Compressor Best Practices

Agenda

• Reciprocating Compressor Losses
• Rod Packing Replacement
• Centrifugal Compressor Losses
• Wet and Dry Seals
• Taking Compressors Offline

Source: CECO
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/h)
  - Worn packing has been reported to leak up to 900 cf/h
Reciprocating Compressor Rod Packing

- A series of flexible rings fit around the shaft to prevent leakage
- Leakage still occurs through nose gasket, between packing cups, around the rings and between rings and shaft
Methane Recovery Through Economic Rod Packing Replacement

• Step 1: Monitor and record baseline leakage and rod wear
  – Establishing baseline leak rates and monitoring rod wear can help to track leakage and evaluate economics

• Step 2: Compare current leak rate to initial leak rate to determine leak reduction expected
  – Leak Reduction Expected (LRE) = Current Leak Rate (CL) – Initial Leak Rate (IL)
  – Example: The current leak rate is measured as 100 cf/h, the same component leaked 11.5 cf/h when first installed

  \[
  \text{LRE} = 100 \text{ cf/h} - 11.5 \text{ cf/h} \\
  \text{LRE} = 88.5 \text{ cf/h}
  \]
Methane Recovery Through Economic Rod Packing Replacement

• Step 3: Assess costs of replacements
  – A set of rings: $700 to $1100
    (with cups and case) $2100 to $3500
  – Rods: $2500 to $4900

• Step 4: Determine economic replacement threshold
  – Partners can determine economic threshold for all replacements

Economic Replacement Threshold (scfh) = \( \frac{CR \times DF \times 1,000}{(H \times GP)} \)

Where:

\( CR = \) Cost of replacement ($)
\( DF = \) Discount factor (%) @ interest \( i \)
\( DF = \frac{i(1 + i)^n}{(1 + i)^n - 1} \)
\( H = \) Hours of compressor operation per year
\( GP = \) Gas price ($/Mcf)
Is Recovery Profitable?

• Step 5: Replace packing and rods when cost-effective
  – Example:

<table>
<thead>
<tr>
<th></th>
<th>Rings Only</th>
<th>Rod and Rings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rings</td>
<td>$1,200</td>
<td>$1,200</td>
</tr>
<tr>
<td>Rod</td>
<td>$0</td>
<td>$7,000</td>
</tr>
<tr>
<td>Gas</td>
<td>$1.5/Mcf</td>
<td>$1.5/Mcf</td>
</tr>
<tr>
<td>Operating</td>
<td>8,000 hrs/yr</td>
<td>8,000 hrs/yr</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Leak Reduction Expected (cfh)</th>
<th>Payback Period (years)</th>
<th>Leak Reduction Expected (cfh)</th>
<th>Payback Period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>1</td>
<td>752</td>
<td>1</td>
</tr>
<tr>
<td>58</td>
<td>2</td>
<td>394</td>
<td>2</td>
</tr>
<tr>
<td>40</td>
<td>3</td>
<td>275</td>
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<td>32</td>
<td>4</td>
<td>216</td>
<td>4</td>
</tr>
<tr>
<td>26</td>
<td>5</td>
<td>180</td>
<td>5</td>
</tr>
</tbody>
</table>

Based on 10% interest rate
Mcf = thousand cubic feet, scfh = standard cubic feet per hour
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/m) to the atmosphere
  - Wet seal emissions of 75 Mcf/day (52 cf/m) have been reported
Centrifugal Compressor Wet Seals

- High pressure seal oil is circulated between rings around the compressor shaft
- Gas absorbs in the oil on the inboard side
- Little gas leaks through the oil seal
- Seal oil degassing vents methane to the atmosphere
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.
- At high rotation speed, gas is pumped between the seal rings 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.
Methane Recovery with Dry Seals

- Dry seals typically leak at a rate of only 0.5 to 3 cf/m
  - Significantly less than the 40 to 200 cf/m emissions from wet seals
- These savings translate to approximately $24,480 to $139,680 in annual gas value
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>Implementation Costs¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seal costs (2 dry @ $14,000/shaft-inch, w/testing)</td>
<td>168,000</td>
<td></td>
</tr>
<tr>
<td>Seal costs (2 wet @ $7,000/shaft-inch)</td>
<td></td>
<td>84,000</td>
</tr>
<tr>
<td>Other costs² (engineering, equipment installation)</td>
<td>128,000</td>
<td>-</td>
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<tr>
<td>Total Implementation Costs</td>
<td>296,000</td>
<td>84,000</td>
</tr>
<tr>
<td>Annual O&amp;M</td>
<td>10,500</td>
<td>77,500</td>
</tr>
<tr>
<td>Annual methane emissions³ (@ $1.5/Mcf; 8,000 hrs/yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 dry seals at a total of 6 scfm</td>
<td>4,320</td>
<td></td>
</tr>
<tr>
<td>2 wet seals at a total of 100 scfm</td>
<td></td>
<td>72,000</td>
</tr>
<tr>
<td>Total Costs Over 5-Year Period ($)</td>
<td>370,100</td>
<td>831,500</td>
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<tr>
<td>Total Dry Seal Savings Over 5 Years</td>
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<tr>
<td>Savings ($)</td>
<td>461,400</td>
<td></td>
</tr>
<tr>
<td>Methane Emissions Reductions (Mcf) (at 45,120 Mcf/yr)</td>
<td>225,600</td>
<td></td>
</tr>
</tbody>
</table>

Notes:
1. Flowserve Corporation
2. Re-use existing seal oil circulation, degassing, and control equipment for wet seal
3. Based on typical vent rates
Is Wet Seal Replacement Profitable?

• Replacing wet seals in a 6 inch shaft beam compressor operating 8,000 hr/yr
  – Net Present Value = $242,543
    • Assuming a 10% discount over 5 years
  – Internal Rate of Return = 41%
  – Payback Period = 24 months
    • Ranges from 16 to 35 months based on wet seal leakage rates between 40 and 200 cf/m

• Economics are better for new installations
  – Vendors report that 90% of compressors sold to the natural gas industry are centrifugal with dry seals
Taking 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 blowdown vents 15 Mcf gas to atmosphere on average

- Isolation valves
  - Leak about 1.4 Mcf/hr on average through open blowdown vents
Methane Recovery Options

• 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%)

• 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 Options contd.

• 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

**All Options Eliminate Methane Vent**

<table>
<thead>
<tr>
<th>Option</th>
<th>Savings (Mcf/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Savings</td>
<td>15 Mcf Vent</td>
</tr>
<tr>
<td>Keep Pressurized</td>
<td>2 Mcf/h</td>
</tr>
<tr>
<td>Route to Fuel System</td>
<td>1 Mcf/h</td>
</tr>
<tr>
<td>Install Static Seal</td>
<td>0.5 Mcf/h</td>
</tr>
</tbody>
</table>

- Fugitive
- Vented - Blowdown
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 $1,250 to $2,250 per compressor

- Option 3: Do not blow down and install static seal
  - Seals cost $700 per rod
  - Seal controller costs $1,400 per compressor
  - Less cost-effective in conjunction with option 2
Is Recovery Profitable?

- Costs and Savings

## Capital Costs and Savings of Reduction Options

<table>
<thead>
<tr>
<th></th>
<th>Option 1: Keep Pressurized</th>
<th>Option 2: Keep Pressurized and Tie to Fuel Gas</th>
<th>Option 3: Keep Pressurized and Install Static Seal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Capital Cost</strong></td>
<td>None</td>
<td>$1,250/compressor</td>
<td>$3,000/compressor</td>
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<tr>
<td><strong>Off-line Leakage Savings</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Base Load</strong></td>
<td>475 Mcf/yr</td>
<td>638 Mcf/yr</td>
<td>625 Mcf/yr</td>
</tr>
<tr>
<td></td>
<td>$713</td>
<td>$957</td>
<td>$938</td>
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<tr>
<td><strong>Peak Load</strong></td>
<td>3,800 Mcf/yr</td>
<td>5,100 Mcf/yr</td>
<td>5,000 Mcf/yr</td>
</tr>
<tr>
<td></td>
<td>$5,700</td>
<td>$7,650</td>
<td>$7,500</td>
</tr>
</tbody>
</table>

Base Load assumes 500 hours offline per year; Peak Load assumes 4,000 hours offline per year. Gas cost = $1.5/Mcf. This table does not include blowdown savings.
Economic Analysis

- Economic comparison of options

<table>
<thead>
<tr>
<th></th>
<th>Facilities Investment</th>
<th>Dollar Savings</th>
<th>Payback</th>
<th>IRR</th>
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<tbody>
<tr>
<td></td>
<td>Base Load</td>
<td>Peak Load</td>
<td>Base Load</td>
<td>Peak Load</td>
</tr>
<tr>
<td>Option 1</td>
<td>$0</td>
<td>$0</td>
<td>$713</td>
<td>$5,700</td>
</tr>
<tr>
<td>Option 2</td>
<td>$1,300</td>
<td>$1,300</td>
<td>$956</td>
<td>$7,650</td>
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<td>Option 3</td>
<td>$3,200</td>
<td>$3,200</td>
<td>$938</td>
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</tbody>
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Assuming $1.5/Mcf Gas Price, 5 year life
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Discussion Questions

• To what extent are you implementing these practices/ options?
• How could these practices/ options be improved upon or altered for use in your operation(s)?
• What are the barriers (technological, economic, lack of information, regulatory, focus, manpower, etc.) that are preventing you from implementing these practices/ options?