Methane Abatement
Best Practices Compliance Plan

François Rongere
April 19th, 2018

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Agenda

• PG&E System and Methane Emission Report

• Compliance Plan Overview

• Best Practices in focus
  – Leak survey frequency (BP#15)
  – Accelerated survey and repair of large leaks (BP#21)
  – Leak backlog reduction (BP#21)
  – Blowdown reduction (BP#3-7)

• R&D and Pilot Programs
• Key Statistics
  – 6,600 miles of gas transmission pipeline
  – 42,700 miles of gas distribution main
  – 4.3 million natural gas customer accounts.
  – Throughput of 820 BCF in 2016

Emission Sources (2016 Report)
Total: 3.1 BCF/y

- 24%
- 22%
- 21%
- 20%
- 9%
- 2%

- Customer Meters
- Distribution M&R Stations
- Distribution Main & Service Pipelines
- Transmission Compressor Stations
- Transmission M&R Stations
- Transmission Pipelines
- Underground Storage

California Pipeline/Storage Facilities:
- PG&E Gas Service Territory
- PG&E Backbone
- PG&E Local Transmission Interconnection
- Compressor Station
- PG&E Gas Storage
- Independent Storage Providers
- Gill Ranch Storage LLC/PG&E
- SoCalGas Storage
- SoCalGas
- Kern/Mojave
- Kern River Gas Transmission
- KRGTHigh Desert Lateral
- Mojave
- North Baja
- Questar Southern Trails
- San Diego Gas & Electric
Compliance Plan Overview

- Substantially reduce methane emissions in 2 years and prepare for deeper abatement towards 2030 goal
- Combination of policies, training, technologies and procedures
- 12 Best Practices are already in place at PG&E, 8 will be implemented in 2018-2019 and 6 will be piloted

<table>
<thead>
<tr>
<th>BP</th>
<th>Description</th>
<th>2018-2019 Cost</th>
<th>Annual Abatement (MMscf)</th>
<th>Cost/Mscf</th>
<th>Cost Benefits per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-7</td>
<td>Blowdown reduction</td>
<td>$ 2,763,223</td>
<td>240</td>
<td>$ 2.5</td>
<td>$ 792,960</td>
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<tr>
<td>15</td>
<td>3-year leak survey cycle</td>
<td>$ 26,237,160</td>
<td>129</td>
<td>$ 81</td>
<td>$ 2,644,500</td>
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<td>16</td>
<td>Special leak survey</td>
<td>$ 3,380,291</td>
<td>2.1</td>
<td>$ 785</td>
<td>$ 42,640</td>
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<tr>
<td>21</td>
<td>Superemitter survey + leak repair</td>
<td>$ 28,902,854</td>
<td>159</td>
<td>$ 70</td>
<td>$ 3,259,500</td>
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<td>23</td>
<td>High bleed pneumatics replacement</td>
<td>N/A</td>
<td>18.4</td>
<td>N/A</td>
<td>$ 60,794</td>
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<tr>
<td>24</td>
<td>Dig-in reduction</td>
<td>N/A</td>
<td>3.1</td>
<td>N/A</td>
<td>$ 63,550</td>
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<tr>
<td></td>
<td><strong>Totals</strong></td>
<td><strong>$ 61,283,528</strong></td>
<td><strong>552</strong></td>
<td><strong>$ 43</strong></td>
<td><strong>$ 6,863,944</strong></td>
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</tbody>
</table>
BP#15 Increase Leak Survey Frequency
The Opportunity

- For a five year survey cycle, there are two times more leaks located in not surveyed areas than in surveyed areas.

- Increasing leak survey frequency
  - reduces the number of unknown leaks
  - leaves less time for leaks to appear
  - raises the cost of leak survey but not of repair on the long term
A 3 year transition period

Year 1 of transition

Surveyed 4 years prior + Surveyed 3 years prior = Year 1 Transition survey area

Theoretical change in emission moving to 3-yr survey

<table>
<thead>
<tr>
<th>Yearly Emissions</th>
<th>4-year survey</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>3-year survey</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unsurveyed area</td>
<td>Surveyed area</td>
<td>Unsurveyed area</td>
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<td>Unsurveyed area</td>
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<tr>
<td>0%</td>
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</table>
BP#21 Accelerate Detection and Repair of Large Leaks
The concept of Super Emitters

- Methane emissions in distribution system are driven by a relatively small number of large leaks named Super Emitters.

- Opportunity for substantially reducing methane emissions by accelerating detection and repair of large leaks.

WSU study: Only 2% of leaks were > 10 scfh but accounted for 56% of total emissions.
The opportunity

• Large leaks are **easy to detect** with mobile surveys (Picarro).

• Even if leak flow rate quantification is still challenging, **solid data** coming from NYSEARCH study is now available to support rigorous calculations
  
  – Two controlled tests at training facilities (PSE&G, SoCalGas)
  
  – Field test in New York suburban area

NYSEARCH Test Unity Plot

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- **1:1 line**
- **$\sqrt{10}$ greater**
- **$\sqrt{10}$ smaller**
Proposed Method

1. Drive Picarro car on an accelerated basis (eg. once a year)
2. Filter out any indications <10 scfh (Picarro’s algorithm)
3. Investigate and repair leaks associated with large indications (>10 scfh)
4. Capture methane abatement from two sources:
   a) **Accelerated detection** and repair of “super emitters”
   b) **Reduction of Emission Factors** for the other leaks

- Leveraging advanced technology to rapidly reduce emission at the lowest cost
- Paving the way to progressively capture deeper reduction by lowering the threshold below 10 scfh and/or increasing mobile survey frequency
R&D work performed in 2017

1. **Analyzed 2016 leak survey data** treated with Picarro’s algorithm

2. **Developed a method** leveraging NYSEARCH validation data and WSU leak distribution information to calculate emission abatement including all uncertainties.

3. **Tested the approach in the field** by directly measuring flow rate of leaks related to large detection by Picarro system (>10 scfh)

**Results:**
Reduction by 22% (120 MMscf) of the Distribution System methane emissions
Additional repair of 300 leaks the first year and 100 leaks the following years
**Cost:** $0.7M/y for additional mobile surveys and $3M for repairs (first year), $1M (following years)

**Cost assumptions:**
- Drive: $100/hr
- Repair: $10,600/leak
Field validation

1. Tested the approach in the field by directly measuring flow rate of large leaks related to large detection by Picarro system (>10 scfh)
   - Found about 2 large detections per week
   - Picarro prediction within order of magnitude of actual leak rate
Field tests results

Field Test - 2017

- Actual vs Measured
- 1:1 Ratio
- 3.16 times Larger
- 3.16 times Smaller
Example 1

Measured: 60 scfh
Actual: 98 scfh
Example 1

Bar-hole locations:
## R&D efforts on Best Practices

<table>
<thead>
<tr>
<th>Category</th>
<th>Best Practice</th>
<th>Title</th>
<th>R&amp;D and Pilots</th>
<th>Budget</th>
</tr>
</thead>
</table>
| **Company Policy**              | BP 5          | Methane Evacuation Implementation Procedures                                                                                          | • Methane Oxidation Catalysts for Reduction of Emissions in Flaring (NYSEARCH)  
• (5.16.n) Methods to Prevent Blowdown of Gas (OTD)                                                                                       | $163k   |
| **Leak Detection**              | BP 16         | Special Leak Surveys                                                                                                                  | • Risk based leak survey method                                                                                              | $2,000k |
|                                 | BP 17         | Enhanced Methane Detection                                                                                                             | • Evaluation of Optical Gas Imaging technologies for detection of distribution system leaks (NYSEARCH)  
• Field test of the new generation of handheld devices based on NASA/JPL high sensitivity technology  
• Integration of NASA/JPL high sensitivity technology methane-ethane detector on small Unmanned Aerial Systems for leak detection and localization (NYSEARCH)  
• Pilot of fixed wing LiDAR-DIAL (Differential Absorption LiDAR) for Transmission System leak detection | $390k   |
|                                 | BP 18         | Stationary Methane Detectors                                                                                                           | • (7.16.f) Evaluation of the state of the art in methane detectors. (OTD)  
• Quantification of methane emissions from Transmission M&R stations                                                                 | $181k   |
|                                 | BP 19         | Above Ground Leak Surveys                                                                                                              | • Pilot of UAS Leak Detection and Quantification  
• Evaluating Gas Imaging Technologies (OTD)  
• Electrochemical Gas Sensor development project (Stanford)                                                                                       | $567k   |
|                                 | BP20          | Leak Quantification & Geographic Evaluation/Tracking                                                                                     | • Stand off Gas Flow Imaging and Analysis System (NYSEARCH)  
• (1.14.d) Field Measurement of Leak Flow Rate (OTD)                                                                                           | $143k   |
## R&D efforts on Best Practices (2)

<table>
<thead>
<tr>
<th>Category</th>
<th>Best Practice</th>
<th>Title</th>
<th>R&amp;D and Pilots</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Leak Prevention</strong></td>
<td><strong>BP 22</strong></td>
<td>Pipe Fitting Specifications</td>
<td>• Reducing Methane Emissions at Threaded Connections (NYSEARCH)</td>
<td>$130k</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>• (5.18.a) Spray-On Leak Seal for Meter Set Joints (OTD)</td>
<td></td>
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<td></td>
<td><strong>BP 23</strong></td>
<td>Prevent/Minimize/Stop Fugitive &amp; Vented Methane Emissions</td>
<td>• (5.17.e) Non-traditional Natural Gas Regulators - Slam shut and Vent Limiting regulators (OTD)</td>
<td>$100k</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Catastrophic Releases, High-Bleed Pneumatics, Blowdowns, etc.)</td>
<td></td>
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</table>

### Budget Distribution

- **Distribution**: 79% ($3,673k)
- **Transmission**: 21% ($952k)

**Total Budget**: $4,626k
Methane Oxidation Catalysts to Avoid Flaring

- Flaring not always feasible because of environmental impact (NOx, noise, infrared radiation)
- “Low temperature oxidation” may be a solution when cross compression is not possible
- Challenge comes from oxidation kinetic
- Stanford has developed advanced catalyst able to yield methane oxidation around 300°C
- Proof of concept in 2018
Smart Pipeline Isolation Technology

- A free-swimming pigging tool with remotely-controlled positioning and plugging functions
- More efficient repair/maintenance operation with significant cost-time saving and emission reduction compared to control fittings
- **Status:**
  - In commercial use for offshore applications over 20 years
  - In tool development and evaluation for the more challenging onshore gas pipeline applications

The conventional way: installation of a control fitting

Smart Pipeline Isolation
Schlieren flow imaging provides integrated characteristics by assessing eddies’ velocity.

- Diffraction index depends on methane concentration.

- May be very effective for most frequent flows in leaks:
  - Transition between laminar and turbulent flows.


Risk Based Leak Survey

- Combining:
  - Risk Ranking developed by DIMP
  - Methane Indications detected by Picarro

Can substantially improve performance of leak surveys
- Leak survey frequency can be adjusted for each plat based on the probability to find leaks
- DIMP provides risk ranking based on history and asset characteristics
- Mobile monitoring indications provide up-to-date confirmation of leak probability
Fixed Wing LiDAR DIAL aerial leak survey

- LiDAR DIAL detector compares absorption in air for two close wavelengths:
  - Centered on methane absorption band
  - Centered in low absorption band area
- Technology has been developed in the 2000s and deployed on helicopters
- Using fixed wing aircrafts reduces cost and improves survey safety
- Tests performed at PG&E have shown good performance for leaks greater than 50 scfh
- Pilot deployment in October 2018
Light handheld and UAV methane detector

- Based on NASA’s detector used on Mars rover Curiosity
- The detector has superior sensitivity (parts per billion) compared to other commercial handheld detectors. It is also lightweight (150g)
- Handheld device for locating leak following Picarro survey is in the industrialization phase
- An UAV (VTOL and fixed wing) has been developed
- Sensor has been adapted to detect ethane and methane
Electrochemical Methane Sensor

- Signature of E/I cycle is specific to the gas.
- Amplitude is proportional to the concentration.
- Easy to fabricate in large volume.
- Low cost.
- Sensor can be stuck at locations were leaks are more common (threads, valves, fittings, etc.)
Continuous monitoring of M&R Stations

- Open Laser Beam measure absorption by methane molecules.
- Wind monitoring is used to estimate methane emissions.
- IoT connection to continuously transfer data to a server.
- Analysis of emission along the time in function of operations and assessment of average emission factors.
- Piloting new technology commercialized by Sensit
Continuous monitoring of M&R Stations:
First Results

Average Emission Each Hour of the Day

<table>
<thead>
<tr>
<th>Time</th>
<th>Emission (ft³/hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00 AM</td>
<td>20</td>
</tr>
<tr>
<td>1:00 AM</td>
<td>15</td>
</tr>
<tr>
<td>2:00 AM</td>
<td>12</td>
</tr>
<tr>
<td>3:00 AM</td>
<td>10</td>
</tr>
<tr>
<td>4:00 AM</td>
<td>8</td>
</tr>
<tr>
<td>5:00 AM</td>
<td>6</td>
</tr>
<tr>
<td>6:00 AM</td>
<td>4</td>
</tr>
<tr>
<td>7:00 AM</td>
<td>2</td>
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<td>1</td>
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<td>10:00 PM</td>
<td>30</td>
</tr>
<tr>
<td>11:00 PM</td>
<td>30</td>
</tr>
</tbody>
</table>

Salinas
Pittsburg
Lomita Park
Salinas Weekly Average Emissions Per Hour

- Week 1 (Nov 26-Dec 2)
- Week 2 (Dec 3-Dec 9)
- Week 3 (Dec 10-Dec 16)
- Week 4 (Dec 17-Dec 23)
- Week 5 (Dec 24-Dec 30)
- Week 6 (Dec 31-Jan 6)
- Week 7 (Jan 7-Jan 13)
- Week 8 (Jan 14-Jan 20)
Thank you

François Rongere
fxrg@pge.com
Calculation steps: Bayesian approach

1. What is the probability for a SE to be detected as a SE
\[ P(A|B) = \frac{P(B|A) \cdot P(A)}{P(B)} \]

Where:
\[ A = \text{an actual leak that is} > 10 \text{ scfh} \]
\[ B = \text{detected by Picarro as} > 10 \text{scfh} \]

2. What is the emission factor of a leak detected as a SE
\[ EF(B) = P(A|B) \cdot EF(A) + (1 - P(A|B)) \cdot EF(\bar{A}) \]

3. Emission abatement:
   - From repair of SE:
     \[ Flow_{abated}(B) = \frac{1}{2} \cdot \text{year} \cdot EF(B) \]
   - From reducing emission factors for other leaks
     \[ EF(\bar{A}) = \frac{EF \cdot N \cdot \left(1 - P(B|A)\right) \cdot \frac{Emission(A)}{Emission}}{N(\bar{A})} \]
### Application to PG&E territory

<table>
<thead>
<tr>
<th>Term</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P(B</td>
<td>A)$</td>
</tr>
<tr>
<td>$P(A</td>
<td>B)$</td>
</tr>
<tr>
<td>$P(B</td>
<td>\bar{A})$</td>
</tr>
<tr>
<td>$EF(B)$</td>
<td>10.3 scfh</td>
</tr>
<tr>
<td>$Flow_{Abated}(B)$</td>
<td>45 Mscf/y</td>
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<tr>
<td>$EF(\bar{A})$</td>
<td>74% * $EF$</td>
</tr>
<tr>
<td>2016 - Abatement</td>
<td>120 MMscf (22%)</td>
</tr>
</tbody>
</table>

Abatement includes adjustment for Picarro has access to ~75% of PG&E distribution system only

**Where:**

A = an actual leak > 10 scfh  
B = estimated by Picarro as > 10scfh
1. Uncertainty of measurements, based on NYSEARCH data, is approximated by a Weibull distribution

2. WSU distribution of leaks is approximated with a Log Normal Distribution

\[ Error = \left| \log_{10} \left( \frac{\text{Measured}}{\text{Actual}} \right) \right| \]
Monte Carlo Simulation

Result:
Abatement: 27%
a) Leak indications qualified as greater than 10 scfh by Picarro represent just over 1% of all indications
b) Leak indications qualified as greater than 10 scfh by Picarro represent more than 25% of all emissions
WSU GRI and CARB (PG&E) Study Data