NOx RECLAIM
Working Group Meeting

March 18, 2014
Agenda

• Welcome & Introductions
• General BARCT Methodology
• Refinery Sector
  – Gas Turbines
  – Review of FCCUs (January 22, 2014 WGM)
• Non-Refinery Sector
  – Gas Turbines
• Discussion
• Schedule/Next Meeting
## Status

<table>
<thead>
<tr>
<th>Category</th>
<th>Control Equipment Manufacturer Contacted</th>
<th>Preliminary Cost Effectiveness Analysis Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCCU</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Cement Kilns</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Gas Turbines (Refinery and Non-Refinery)</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Coke Calciner</td>
<td>X</td>
<td>In progress</td>
</tr>
<tr>
<td>Glass Furnaces</td>
<td>X</td>
<td>In progress</td>
</tr>
<tr>
<td>Metal Melting Furnaces</td>
<td>In progress</td>
<td>In progress</td>
</tr>
<tr>
<td>SRU/Tail Gas</td>
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<td>In progress</td>
</tr>
<tr>
<td>ICEs</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Boilers/Heaters</td>
<td>X</td>
<td>In progress</td>
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</table>
Overall BARCT Methodology

• Technical Feasibility

• Cost Effectiveness
  – Incremental Cost Effectiveness Based on 2000/2005 BARCT
  – Based on 2011 activity
Refinery Sector
Preliminary Analysis
Gas Turbines
Overview of Emission Control Technologies

- Water or Steam Injection: 50 ppmv - 20 ppmv
- Dry Low NOx (DLN), Dry Low Emissions (DLE), Cheng Low NOx (CLN): 25 ppmv - 9 ppmv
- Selective Catalytic Reduction: 9 ppmv - 2 ppmv
- Other Types of Control
  - CO Oxidation Catalysts for CO Emissions
  - Ammonia Slip Catalysts for NH3 Slip, CO, HC Emissions
Proposed BARCT for Gas Turbines

• 2 ppmv NOx

• SCR with as applicable
  – Dry Low NOx (DLN) / Dry Low Emissions (DLE)
  – Cheng Low NOx (CLN)

• Implementation Schedule
  – 2017 to 2020
  – May Consider Synchronization with Refinery’s Turnaround Schedule
Development of Cost Data

Refinery’s Information
(Present Worth Value)

• 7 MW Gas Turbine
  – Total Installed Costs (TIC) = $1.83 M
  – Annual Operating Costs (AOC) = $93,000
  – Catalysts Replacement (CR) = $435,500 every 10 years
  – PWV = TIC + (15.62*AC) + (1.14*CR) = $3.80 M

• 83 MW Gas Turbine
  – Total Installed Costs (TIC) = $5.90 M*
  – Annual Operating Costs (AC) = $375,000*
  – Catalysts Replacement (CR) = $950,000 every 10 years*
  – PWV = $15.5 M*

  (* adjusted up 20% to match cost effectiveness provided in permit application)
Development of Cost Data
Manufacturers’ Information
(Present Worth Value)

- 7 MW and 83 MW Gas Turbines
- SCR and CO Catalysts
- SCR and Ammonia Slip Catalysts
  - Dual Function. Equivalent or Better Control Efficiency for NOx, CO, HC Compared to Conventional SCR and CO Catalysts at Less Costs
  - Extend SCR Life and Achieve Low Ammonia Slip
Development of Cost Data

EPA’s Information
(Present Worth Value)

• “Alternative Control Techniques Document – NOx Emissions from Stationary Gas Turbines”
  EPA-453/R-93-007

• Equations to Estimate TIC, AOC, and CR

• 80% - 90% Reduction Equivalent to Reducing to 2 ppmv from 10 ppmv or 20 ppmv
Development of Cost Data
DOE’s Information
(Present Worth Value)

• “Cost Analysis of NOx Control Alternatives for Stationary Gas Turbines”, November 5, 1999

• TIC and AOC for 5 MW, 25 MW, and 150 MW Gas Turbines

• 80% - 90% Reduction Equivalent to Reducing to 2 ppmv from 10 ppmv or 20 ppmv
PWV of SCR for Gas Turbines

\[ y = 0.2372x + 1.7376 \]

\[ R^2 = 0.9461 \]

- DOE, $11 M
- EPA, $22 M
- Manufacturer, $19 M
- Refinery, $16 M
- DOE, EPA, Refinery, $4 M
- Manufacturer, $2 M
- DOE, $41 M

PWV (\$ million) vs. Turbine Rating (MW)
# Proposed BARCT Cost Effectiveness @ 2 ppmv

**Incremental Cost Effectiveness with SCR**

<table>
<thead>
<tr>
<th>Unit Rating Profile (MW)</th>
<th>2000/2005 BARCT Level (lbs/mmScft)</th>
<th>PWV ($M)</th>
<th>Emission Reduction from 2000/2005 BARCT (tpd)</th>
<th>CE for 2014 BARCT ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>(b)</td>
<td>(c)</td>
<td>(e)</td>
<td>(f)</td>
</tr>
<tr>
<td>59</td>
<td>62.27</td>
<td>15.7</td>
<td>0.210</td>
<td>8,210</td>
</tr>
<tr>
<td>46</td>
<td>62.27</td>
<td>12.6</td>
<td>0.310</td>
<td>4,472</td>
</tr>
<tr>
<td>30</td>
<td>62.27</td>
<td>8.9</td>
<td>0.200</td>
<td>4,851</td>
</tr>
<tr>
<td>23</td>
<td>62.27</td>
<td>7.2</td>
<td>0.140</td>
<td>5,631</td>
</tr>
<tr>
<td>83</td>
<td>62.27</td>
<td>4.8</td>
<td>0.600</td>
<td>870</td>
</tr>
<tr>
<td>No Turbines/Duct Burners = 21</td>
<td>Total PWV = $97.68 M</td>
<td>Total Reductions = 4.14 tpd</td>
<td>Average CE = 2,692 $/ton (g)</td>
<td></td>
</tr>
</tbody>
</table>

(a) All gas turbines and all SCRs at the refineries were installed ≥ 25 years ago.
(b) 2000/2005 BARCT Level from Table 1 of Rule 2002.
(c) $\text{PWV} = (0.2372 \times \text{MW}) + 1.7376$
(d) Costs for additional SCR catalysts to get from 10 ppmv to 2 ppmv.
(e) Emission Reduction = Emissions @ 2000/2005 BARCT Level − Emissions @ 2 ppmv
where Emissions @ 2000-2005 BARCT Level = 2011 Fuel Gas Usage (mmScft/yr) \times 62.27 (lb/mmScft)
\[\text{Emissions} @ \text{2 ppmv} = \text{2011 Emissions} \times (2 \text{ ppmv} / \text{2011 NOx Level in ppmv})\]
(f) CE = PWV/Emission reductions from 2000-2005 BARCT = (c)/(e \times 365 \times 25)
(g) CE (DCF Method) = $2692 per ton. CE (LCF Method) = $4500 per ton for 25 years life and 4% interest rate.
Refinery Sector Review for FCCUs

(Summary from January 22, 2014 WGM)
Proposed BARCT for FCCUs
(Summary from January 22, 2014 WGM)

• 2 ppmv NOx

• Control Technology
  – SCR
  – LoTOx
  – NOx Reducing Additives in combination
    with SCR or LoTOx

• Implementation Schedule
  – 2017 to 2020
  – May Consider Synchronization with Refinery’s
      Turnaround Schedule
### Proposed BARCT Cost Effectiveness @ 2 ppmv

Incremental Cost Effectiveness with SCR or LoTOx

*(Summary from January 22, 2014 WGM)*

<table>
<thead>
<tr>
<th>Equipment</th>
<th>2005 BARCT Level</th>
<th>Incremental PWV ($M)</th>
<th>Incremental Emission Reduction from 2005 BARCT Level (tpd)</th>
<th>CE for 2014 BARCT ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCCUs with SCR</td>
<td>85% reduction</td>
<td>13</td>
<td>0.43</td>
<td>3,444</td>
</tr>
<tr>
<td>FCCUs with LoTOx</td>
<td>85% reduction</td>
<td>-14</td>
<td>0.43</td>
<td>-3,521</td>
</tr>
</tbody>
</table>

(a) 2005 BARCT level from Table 3 of Rule 2002

(b) Incremental difference in costs of control equipment for 85% reduction and control equipment for 2 ppmv

(c) Incremental emission reductions = Emissions @ 2005 BARCT – Emissions @ 2ppmv

(d) \( \text{CE} = \frac{(b)}{(c \times 365 \times 25)} \) for DCF method. For LCF, \( \text{CE} = $5,700 - $5,900 \) per ton
Non-Refinery Sector Preliminary Analysis
Gas Turbines
Non Refinery Gas Turbines (From 38 Facilities)

Proposed emission level: 2 ppm

2000/2005 BARCT Level: 17 ppm
Cost Analysis for Gas Turbines

• Onshore gas turbines fired on natural gas
• Offshore (OCS) gas turbines fired on process gas or diesel
• Tier-1 Level 2000 (0.06 lb/mmBtu)
• Proposed BARCT level: 2 ppm @15% O₂
• For inlet NOx below 25 ppm, 2 ppm is achievable
• For inlet NOx above 25 ppm, 95% reduction is achievable
• Proposed Control technology: Selective Catalytic Reduction (SCR)
BARCT Emission Level

• Based on inlet concentration range for units emitting at or above 25 ppm (~50-160 ppm)

<table>
<thead>
<tr>
<th>Inlet NOx @15%O2</th>
<th>BARCT Emission Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25 ppm</td>
<td>2 ppm</td>
</tr>
<tr>
<td>At or above 25 ppm</td>
<td>95% Reduction*</td>
</tr>
</tbody>
</table>

* Further evaluation ongoing

• Implementation Schedule
  • 2017-2020
Cost Analysis for Gas Turbines

• SCR vendor equipment costs include:
  • Ductwork, NH₃ injection hardware, catalyst, PLC system, tempering air/mixing system, and CFD flow modeling

• Installation costs were calculated to be 200% of the equipment costs (400% for OCS)

• Total Installed Cost (TIC) includes equipment plus installation

• Vendor-supplied annual costs (AC) include NH₃ usage, catalyst replacement, and power.
  • Catalyst replacement every 3 years
Cost Analysis for Gas Turbines

- Present Worth Value (PWV) assumes a 4% interest rate and a 25-year equipment life
  \[ PWV = TIC + (15.622 \times AC) \]
- Emission Reductions (ER) for this category
  - 1.71 tons per day
- Cost Effectiveness = \( \frac{PWV}{(ER \times 365 \times 25)} \)
- Cost Effectiveness Range
  - DCF range: $3,100 - $26,000 / ton
  - LCF range: $5,000 - $42,000 / ton

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PWV of SCR for Non-Refinery Gas Turbines
(Inlet ppm at or above 25 ppm to achieve a 95% reduction of 3-8 ppm)*

\[ y = 0.2529x + 2.8203 \]

\[ R^2 = 0.947 \]

* Further evaluation ongoing
PWV of SCR for Non-Refinery Gas Turbines
(Inlet ppm below 25 ppm to achieve 2 ppm)

\[ y = 0.0638x + 3.7553 \]

\[ R^2 = 0.6743 \]
## Proposed BARCT Cost Effectiveness

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>1-140</td>
<td>0.06 lb/MMBTU</td>
<td>3-14</td>
<td>1.71</td>
<td>$3,000 - $26,000 Average: ($13,198/ton)</td>
</tr>
</tbody>
</table>

* Cost Effectiveness LCF range: $5,000 - $42,000 / ton
Next Steps

• Complete BARCT Analysis
• Schedule next meeting April/May 2014
• Ongoing individual meetings to review BARCT
Contact

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