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Norton Engineering Consultants, Inc.

SCAQMD NOx RECLAIM - BARCT Feasibility and Analysis Review

Non-Confidential Final Report No. 14-045-4

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Norton Engineering Consultants (NEC) has been commissioned by the South Coast Air Quality Management District (SCAQMD) to provide commentary reviews and recommendations on the analysis reports developed by SCAQMD staff regarding the commercially available NOx reduction technologies and their cost effectiveness analysis. These analyses will form the basis for the amendments to the regulation of Regional Clean Air Incentives Market (RECLAIM) for NOx that the SCAQMD is proposing to achieve additional NOx reductions in the South Coast Basin.

NEC has reviewed five draft reports and cost estimate provide by SCAQMD staff, including

- Fluid Catalytic Cracking Units (FCCU)
- Refinery Boilers and Heaters
- Gas Turbines and Duct Burners
- Coke Calciner
- Sulfur Recovery and Tail Gas Treatment Units

NEC and the SCAQMD staff visited six refineries in the District during November 21 to 30, 2014 in order to review space constraints around existing equipment that will affect the installation of additional NOx reduction equipment. NEC also had the opportunity to meet the refinery staffs and reviewed the operation and performance of some of their existing NOx reduction equipment. NEC also listened to their comments and ideas about the required equipment changes to achieve the new regulations. Additionally, NEC received comments regarding their perceived difficulties in installing the expected large number of projects for NOx reduction in the District.

NEC visited the following, focusing on FCCUs and heaters/boilers

- 6 refineries: ExxonMobil, Phillips66, Chevron, Paramount, Tesoro LAR, and Valero
- 2 FCCUs at 2 refineries (Phillips66 and Valero)
- 100+ Heaters and boilers at the refineries
- 2 Gas turbines and duct burners (Paramount and Tesoro LAR)
- 3 Sulfur recovery/tail gas incinerators (Paramount and Tesoro LAR)
- 20+ Selective Catalytic Reduction units (SCRs)

After the visits, NEC has made a comprehensive evaluation of the costs of control technologies involved, provided a best estimate on the size and the space needed for the control equipment, and the time needed to install control technologies to achieve maximum emission reduction levels that should be targeted at this stage. Equipment sizes and space estimates are provided in the Confidential Report. In the present report, the BARCT level recommendations and cost economics are provided based on the information made available to NEC by the refineries, equipment manufacturers, and SCAQMD. The basis for estimating the cost of NOx control projects are provided by NEC to assist the District in setting the BARCT levels.

1. Fluid Catalytic Cracking Units

There are five refineries that operate six fluid catalytic cracking units (FCCU) in the SCAQMD: ExxonMobil, Phillips66, Chevron, Tesoro LAR, and Valero. The two major control technologies that were considered feasible by the SCAQMD for NOx control in FCCUs are Selective Catalytic Reduction (SCR) and LoTOx^{TM}.

Three of the existing FCCUs operate with an SCR and have current NOx emission levels between 1.2 ppmv and 15 ppmv at 3% O_2. The other three FCCUs do not have major NOx control devices and their emission levels range between 13 ppmv and 45 ppmv. Due to the good operating experience with SCRs in the region and the lack of experience with LoTOx^{TM} at the 2 ppmv NOx level, NEC feels the preferred technology for FCCU NOx control should be SCR. This technology also appears to be that preferred by the refineries due to their experience to date. The proposed BARCT level of 2 ppmv NOx @ 3% O_2 is achievable with SCR.

1.1 Cost Summary

The following curves show the Total Investment Cost (TIC) and Present Worth Value (PWV) for the FCCUs. The TIC includes all material, labor, engineering, construction, and infrastructure costs for a project and is based on the plant startup in the present year (2014). The PWV is a SCAQMD defined terminology described in the following equation assuming 4% interest rate and 25 years SCR life with 5 years catalyst replacement cycle.

$$PWV = TIC + (15.62 \times AC) + (2.52 \times CR)$$

where:

TIC is the Total Installed Costs, $
AC is the Annual Operating Costs, $
CR is the Catalyst Replacement Costs, $

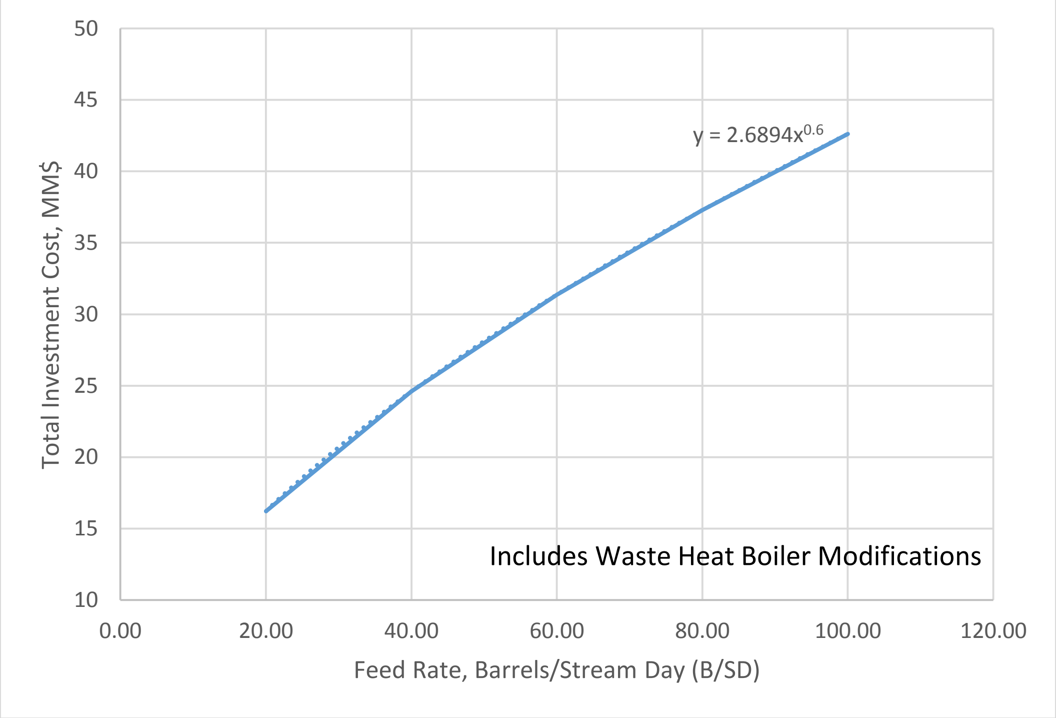

Figure 1: Total Investment Cost for FCCU

The following is the basis of the above curve.

- The cost estimate basis is for a specific FCCU SCR in the region (Refinery 9), for which process flows, temperatures, and pressures were available. A budget type design and quote at 60 Barrels per Stream Day (B/SD) for this SCR was obtained from a prominent FCCU SCR vendor (Manufacturer C). NEC used a 10 ft/sec velocity in sizing the SRC boxes.
- Sizes and costs for FCCU SCRs at other flow rates were developed by prorating B/SD capacity to the power of 0.6. Catalyst volume was prorated directly to the flow rate in B/SD. Costs for the CEMS systems and ammonia injection facilities were independent of capacity and so the same for all units.
- Material costs for the Refinery 9 SCR box were provided by Manufacturer C and adjusted to the NEC's design basis of three beds. The initial catalyst supply cost ($/volume) was provided by Manufacturer C and is also included as a material cost.
- An SCR consists of three vertical catalyst beds using operating at 650^{o}F.

- Based on NEC's extensive experience, these costs were then increased by a bid conditioning factor of 1.35 to account for manufacturer cost bias and upgrading to plant standards.

- Modifications to the existing FCCU waste heat boilers are needed to supply flue gas at the correct SCR operating temperature and to return the gas to waste heat boiler for final heat recovery as at present.

- Costs for ammonia injection facilities and a skid to vaporize 29% ammonia solution are included.

- Costs for an 11,000 gallon aqueous ammonia storage tank are included, based on a 7,000 gallon tank truck delivery as advised by the prominent Southern California ammonia supplier.

- A new CEMS system is installed to meet the new requirement to measure NOx at 2 ppmv level.

- Infrastructure costs and contingency were included in the TIC factor that was applied. This factor is based on NEC's project experience and accounts for the average difficulty of installing new facilities in an existing large refinery operating unit.

- Any of the equipment demolition costs that might be required by Facility 7 are not included.

- Sufficient plot space at grade is available for the SCR installation.

- NEC's TIC estimate was compared with two actual FCCU SCR costs as reported by two refineries (Facilities 1 and 5) in the District. The NEC TIC estimate is within the range of these two actual SCR costs.

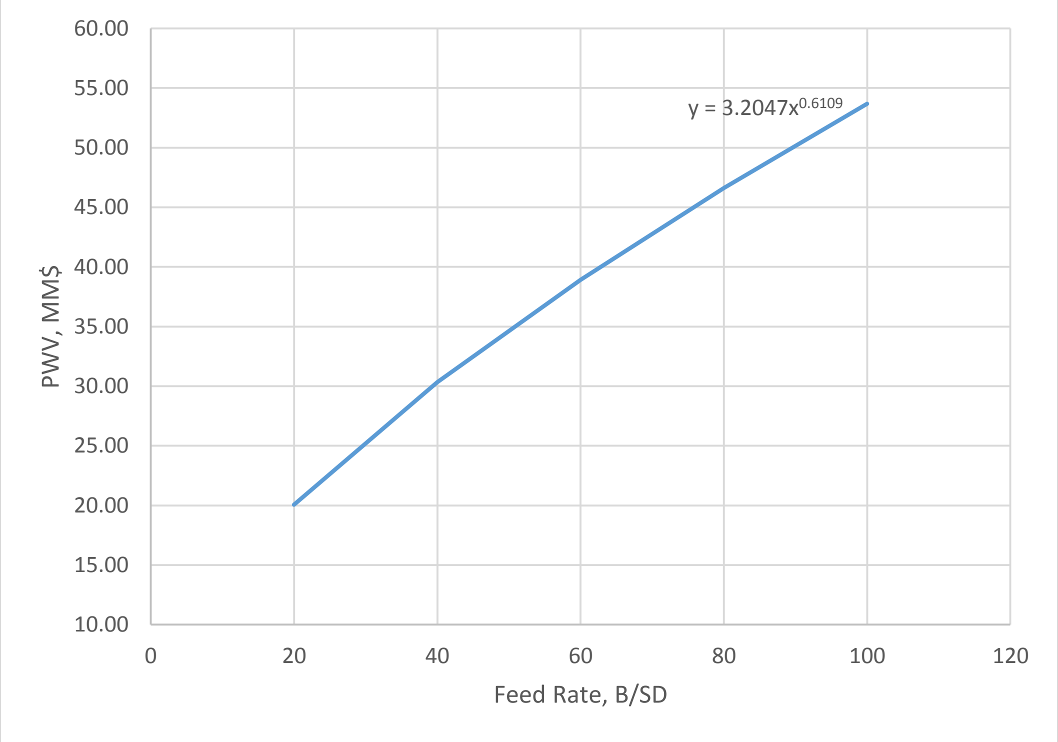

Figure 2: PWV for FCCUs

The following is the basis for the above PWV curve.

- TIC is from the previous curve.
- Maintenance is 0.35% of TIC.
- Ammonia cost is $475 /ton for 29% aqueous NH3 solution. Actual cost varies depending on FCCU flow rate. NOx level in flue gas is assumed 45 ppmv at 3% O_2.
- Catalyst cost is 1.0 MM$ for a 60,000 B/SD FCCU. For other sizes, the costs are prorated directly.
- Miscellaneous utility costs for the ammonia skid are included.

1.2 PWV Comparison

The following table compares the PWV values provided by SCAQMD at the January 22, 2014 Working Group Meeting to those of NEC for various refineries.

Facility ID	PWV AQMD's Estimate ($ M)	PWV NEC's Estimate ($ M)
5	33	46 (Note 1)
6	57	46 (Note 2)
7	27	42
4	16	38
9	19	39
Total	152	211

Note 1: The SCR costs for this facility is probably over estimated because NEC did not see nor receive any additional details of the SCR at the facility site visit. There may be capacity in the existing SCR that would reduce the costs based on the information provided to NEC at this stage.

Note 2: The SCR costs for this facility is probably over estimated because NEC did not see nor receive any additional details of the SCR at the facility site visit.

1.3 Project Schedules

NEC estimates that it could take about 2 years to fully implement an SCR project after the plant commits to the project. This time includes process engineering work to firm up and fully define the relevant operating parameters, the preliminary plant layout, and the preparation of a process design package. The next phase called Detailed Engineering would consist of obtaining SCR manufacturer's bids, selecting the preferred manufacturer, and completing all the detailed engineering, including other equipment, infrastructure, and all purchasing. Finally, construction and start-up would occur. However, due to the large number of expected NOx RECLAIM projects in the District, NEC feels that this time frame could easily extend to 3 years.

2. Refinery Boilers and Heaters

NEC visited over 100 heaters and boilers in six refineries in the SCAQMD, namely, ExxonMobil, Phillips66, Chevron, Paramount, Tesoro LAR, and Valero. The major control technology used for NOx control in refinery heaters and boilers is Selective Catalytic Reduction (SCR). NEC feels that the other technologies that were considered feasible by the SCAQMD do not have sufficient achieved-in-practice demonstration and experience in refinery applications firing refinery fuel gas (RFG) at the time of this review. Also, the refineries are comfortable with the use of SCRs and NEC feels that they would have a difficult time in using other technologies.

The goal of the new BARCT regulations is to achieve 2 ppmv NOx at 3% O_2 and 5 ppmv ammonia slip. Most heaters and boilers in the District use low NOx burners and those that do not have an SCR currently operate at about 60 ppmv NOx emission. One of the challenges in achieving 2 ppmv NOx level is the variability in heater performance when firing RFG. This is a major concern of most of the refineries. It is not entirely clear what causes the problems with NOx control on heaters burning RFG, but it could be that the sudden swings in fuel gas composition result in high level of NOx from combusting hydrogen and olefins as these components burn hotter than other components in the fuel gas.

NEC feels that 2 ppmv NOx at 3% O_2 and 5 ppmv ammonia slip is an achievable BARCT level. If the refinery heaters and boilers were only burning natural gas, this 2 ppmv NOx level could be achieved by installing three SCR catalyst beds in series. However, to improve the NOx removal efficiency while burning RFG, which is necessary as all of the heaters routinely operate in this mode, NEC recommends the addition of an Ammonia Slip Catalyst (ASC) bed downstream of the third SCR bed to enhance performance. The ASC bed will permit the SCR to operate with higher ammonia loadings when needed and still guarantee the 5 ppmv ammonia slip. An additional complication in controlling the NOx level on refinery heaters is that many of them have duties that change significantly over short periods of time due to process and feed variations. The ASC bed will also alleviate this difficulty.

The refinery heaters and boilers that have SCRs currently operate at 1.6 ppmv to 20 ppmv NOx. The large heater operating at 1.6 ppmv currently meets the proposed BARCT guidelines. However, we did not see this heater during our site visits. Therefore, it was not possible to conduct an in-depth evaluation of this SCR to understand the operating parameters and catalyst characteristics that allow it to achieve such a low NOx level. Also, in comparing recent performance data provided to the SCAQMD versus data in the permit application, it appears that this heater is now operating at only about 75% of its maximum firing duty, thus enhancing residence time and its NOx reduction capability. Since we were not able to understand the full performance characteristics of this heater, NEC's recommendations regarding the design parameters needed to achieve the 2 ppmv BARCT proposal were developed from the data supplied by one of the major the catalyst vendors as explained above in FCCU write-up.

The vast majority of the heaters do not have SCRs and operate at about 60 ppmv NOx. During our site visits, we were able to locate available space, whether at grade or at elevated location, for the installation of SCRs on just about every heater. Some have sufficient space readily available, while many were a little tight on space. Vertically mounted SCRs at grade or at an elevation will be required for these latter cases. The following curve of TICs reflects these cases where a moderate degree of difficulty will be encountered when installing the SCR. A few of the heaters will be difficult to install an SCR, and their TIC costs will be about 20% higher than the curve value.

2.1 Costs Summary

The following curves show the Total Investment Cost (TIC) and Present Worth Value (PWV) for the heaters and boilers. The TIC includes all material, labor, engineering, construction, and infrastructure costs for a project and is based on the plant startup in the present year (2014). The PWV is a SCAQMD defined terminology described in the following equation assuming a 4% interest rate and a 25 year SCR life with a 5 year catalyst replacement cycle.

$$PWV = TIC + (15.62 \times AC) + (2.52 \times CR)$$

where:

TIC is the Total Installed Costs, $
AC is the Annual Operating Costs, $
CR is the Catalyst Replacement Costs, $

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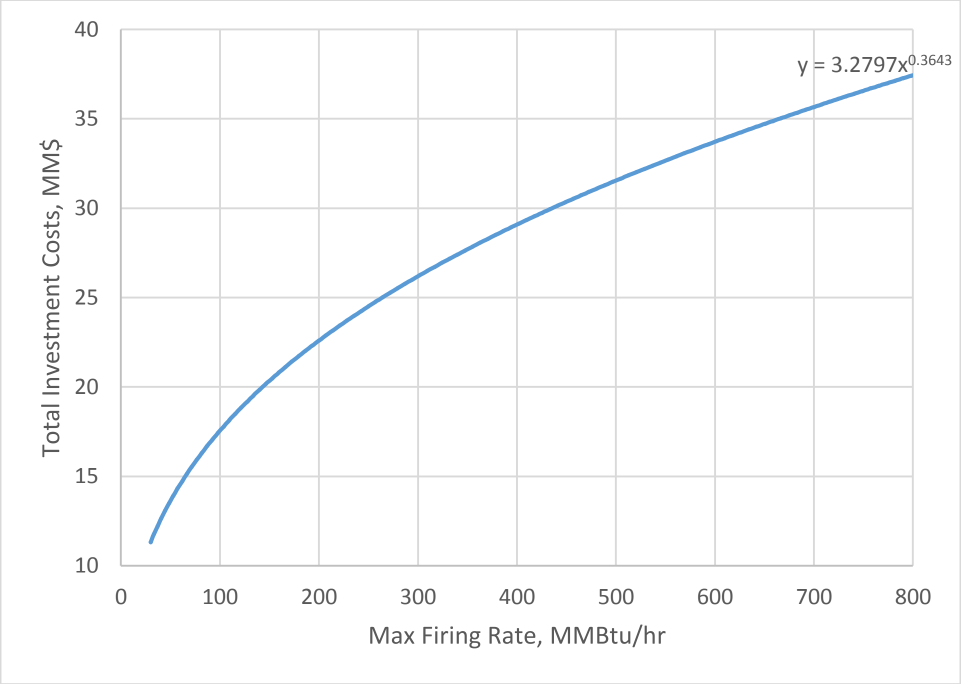

Figure 3: Total Investment Cost for Heaters and Boilers

The following is the basis of the above curve.

- The base SCR box size (three vertical catalyst beds) was prorated from the same, previously discussed, FCCU SCR budget type size obtained from the prominent SCR vendor. This was then increased to add the fourth Ammonia Slip Catalyst (ASC) bed. The prorated cross section area was calculated at 10 ft/sec velocity and 650 ^{o}F operating temperature.
- Process calculations were done for heaters to determine the actual flue gas volumetric rate at the reported stack temperatures. Heater SCR box costs were then prorated from the FCCU budget type SCR box quote based on actual volumetric flow rates. This calculation is based on 0.6 power law function.
- The same material costs for the FCCU SCR box provided by Manufacturer C (of the FCCU SCRs) were used and adjusted to the NEC’s heater and boiler design basis of four beds. The initial catalyst supply cost ($/volume) was also provided by Manufacturer C (of the FCCU SCRs) and is also included as a material cost.

- Based on NEC's extensive experience, these costs were then increased by a bid conditioning factor of 1.35 to account for manufacturer cost bias and upgrading to plant standards.
- Costs for a single induced draft fan were included. The size of the ID fan in BHP was estimated at 1.6 times the heater maximum firing rate in MMBtu/hr.
- Costs for ammonia injection facilities and a skid to vaporize 29% ammonia solution are included.
- Costs for an 11,000 gallon aqueous ammonia storage tank are included, based on a 7,000 gallon tank truck delivery as advised by the prominent Southern California ammonia supplier.
- A new CEMS system is installed to meet the new requirement to measure NOx at 2 ppmv level.
- Infrastructure costs and contingency were included in the TIC factor that was applied. This factor is based on NEC's project experience and accounts for the average difficulty of installing new facilities in an existing large refinery operating unit.
- Any of the equipment demolition costs that might be required by a few refineries are not included.
- The curve represents an installation having an average difficulty in constructing the new SCR. This implies that a close and clear ground level open area was not completely available.
- NEC's TIC estimate was compared to SCR TIC costs estimate as reported by one of the major refineries (Facilities 1 and 5) in the District we visited. The NEC TIC estimate is within the range of the values they provided for numerous heaters.

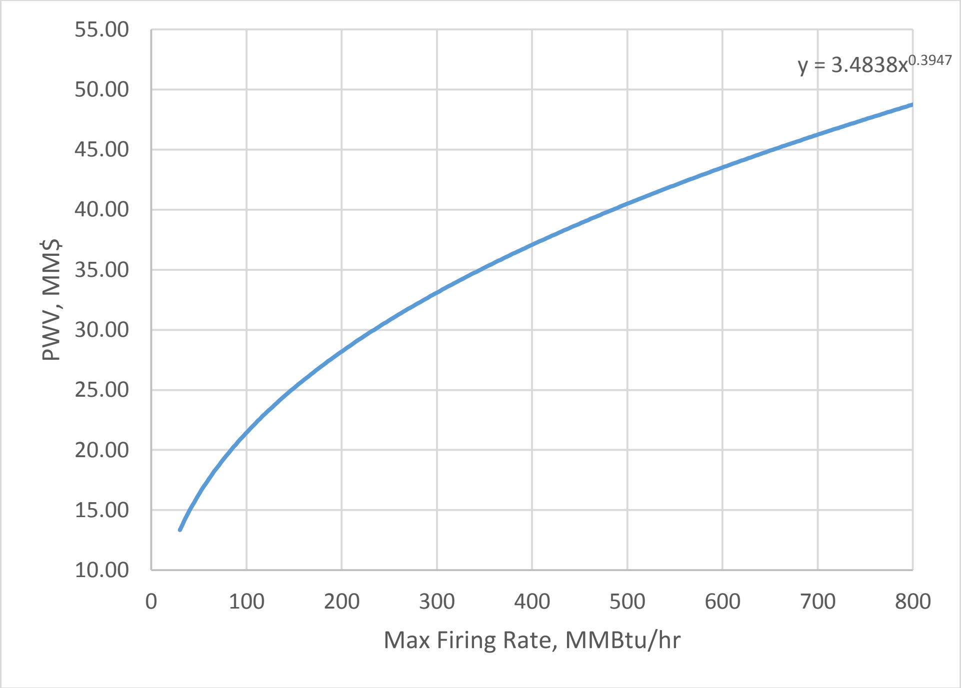

Figure 4: PWV for Heaters and Boilers

The following is the basis for the above PWV curve.

- TIC is from the previous curve.
- Maintenance is 0.35% of TIC.
- Ammonia cost is $475 /ton for 29% aqueous NH_3 solution. Actual cost varies depending on heater flue gas flow rate. NOx level in flue gas is assumed 60 ppmv at 3% O_2.
- Catalyst cost is $690k for a 300 MMBtu/hr heater. For other sizes, the costs are prorated directly.
- Miscellaneous costs for ammonia skid are included.

2.2 Project Schedules

NEC estimates that it could take about 2 years to fully implement an SCR project after the plant commits to the project. This time includes process engineering work to firm up and fully define the relevant operating parameters, the preliminary plant layout, and the preparation of a process design package. The next phase called Detailed Engineering would consist of obtaining SCR manufacturer's bids, selecting the preferred manufacturer, and completing all the detailed engineering, including other equipment, infrastructure, and all purchasing. Finally, construction and start-up would occur. However, due to the large number of expected NOx RECLAIM projects in the District, NEC feels that this time frame could easily extend to 3 years.

3. Gas Turbines and Duct Burners

NEC only briefly visited two gas turbines in the SCAQMD: Paramount and Tesoro LAR. The major control technology used for NOx control in these gas turbines is Selective Catalytic Reduction (SCR) and modern combustion technology, such as Dry Low NOx (DLN) combustors.

The goal of the new BARCT regulations is to achieve a 2 ppmv NOx level at 15% O_2 and 5 ppmv ammonia slip. Most of the gas turbines currently operating in the District operate with NOx levels of 6 ppmv or less. All gas turbines in the District are equipped with SCRs. The SCR is nestled between the boiler tube bank and economizer, and occupies between 10 to 20 feet of length. Generally, SCR designs in gas turbine service usually allow room for the addition of about 50% more catalyst. With the use of the recently developed modern catalysts, there is a high probability that the 2 ppmv level can be achieved by adding catalyst in existing SCRs. However, NEC only has limited information on the design and operating capability of the District's gas turbines. Refinery 1 which has an 83 MW gas turbine has reported that there is space available in their SCR to upgrade with modern catalysts. In our limited discussion with vendors, they feel that space is adequate to upgrade most existing SCRs to the new 2 ppmv BARCT level. Therefore, NEC feels that most gas turbines can achieve 2 ppmv NOx level with just catalyst modification and additions.

The alternative approach to reducing the NOx levels, where space for additional catalyst is not available in the existing SCR footprint, would be to install a larger, off-set SCR in a vertical orientation. This would involve providing a substantial amount of very large duct work from the gas turbine outlet and probably would involve relocating the economizer coil into the new duct work. The SCR outlet would then be returned to the existing stack. The cost of this type of retrofit would be approximately the same as the cost for installing an SCR on a refinery fired heater of equivalent flue gas rate. As NEC was not requested to visit all of the gas turbines in the District refineries, NEC cannot make a judgment as to which ones will need an off-set SCR.

3.1 Costs Summary

The following curves show the Total Investment Cost (TIC) and Present Worth Value (PWV) for the gas turbines. The TIC includes all catalyst, material, labor, engineering, construction, and infrastructure costs for a project and is based on the plant startup in the present year

(2014). The PWV is a SCAQMD defined terminology described in the following equation assuming 4% interest rate and 25 years SCR life with 5 years catalyst replacement cycle.

$$PWV = CR + (15.62 \times AC) + (2.52 \times CR)$$

where:

AC is the Annual Operating Costs, $
CR is the Catalyst Replacement Costs, $

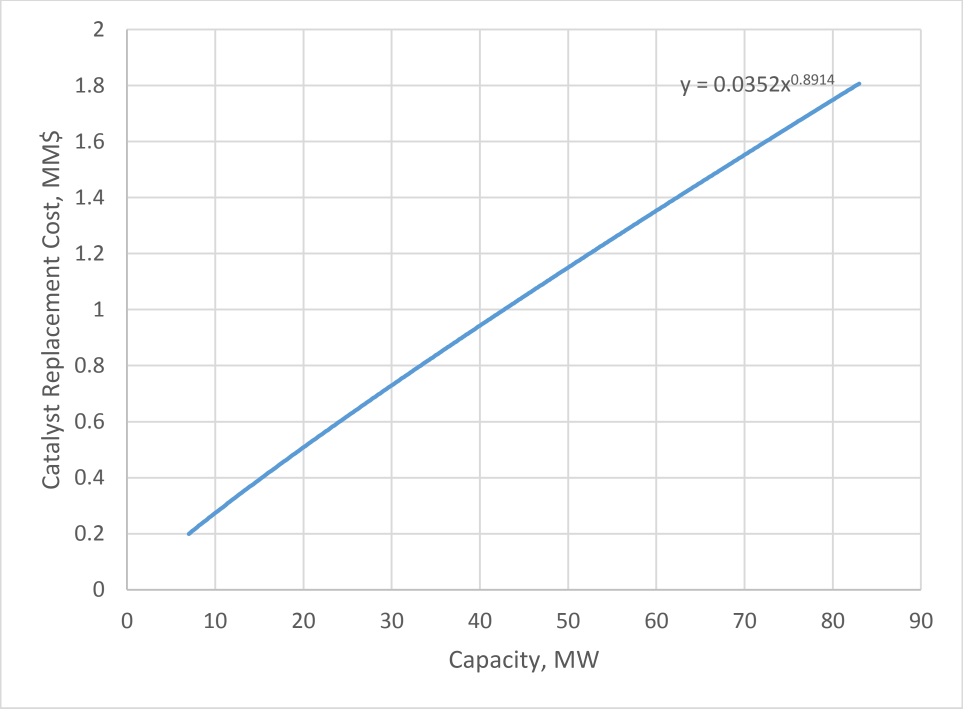

Figure 5: Catalyst Replacement Cost for Gas Turbine

The following is the basis of the above curve.

- Catalyst costs that NEC used were supplied to the District by a catalyst manufacturer (Manufacturer A for Refinery Gas Turbines). The catalyst costs were then increased by a bid conditioning factor of 1.1 to account for manufacturer cost bias.
- Labor costs for catalyst installation were included.
- Existing ammonia facilities are assumed to be sufficient to supply and vaporize the 29% ammonia solution. Ammonia consumption increases from present value by about 10% to achieve the lower NOx level.

- The existing CEMS systems are assumed to be adequate since they currently monitor 2 to 6 ppmv NOx range.
- NEC's catalyst replacement curve was generated from the Refinery 1 data. The catalyst cost for the other refineries was prorated directly based on the capacity of the gas turbines.
- Existing ammonia injection grids are assumed to provide adequate ammonia distribution without modification.

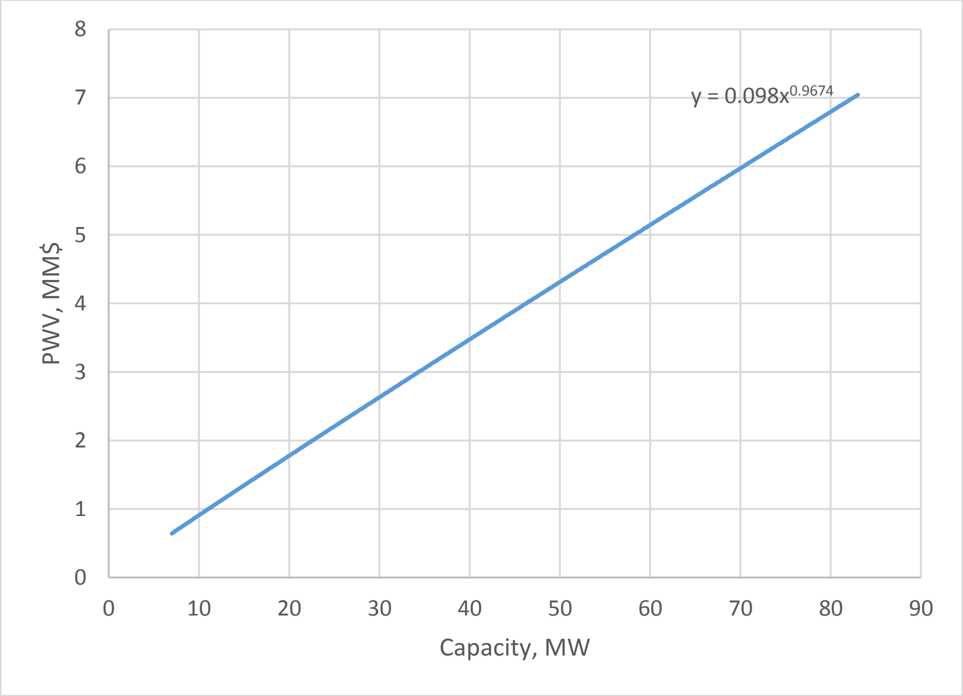

Figure 6: PWV for Gas Turbines

The following is the basis for the above PWV curve.

- Catalyst replacement costs is from the previous curve.
- Maintenance is 0.35% of catalyst costs.
- Ammonia cost is $475 /ton for 29% aqueous NH_3 solution. Only the additional ammonia usage is included.
- Catalyst cost is $1.5 MM for an 83 MW gas turbine. For other sizes, the costs are prorated directly.

3.2 PWV Comparison

The following table compares the PWV values provided by SCAQMD at the January 22, 2014 Working Group Meeting to those of NEC for various refineries.

No of Units	Rating	Current NOx level (ppmv)	PWV per unit estimated by AQMD ($ M)	PWV per unit estimated by NEC ($ M)
1	59	5.7	15.7 (new SCR)	5.1 (add catalysts)
3	46	3-4	12.6 (new SCR)	4.0 (add catalysts)
2	30	6	8.9 (new SCR)	2.6 (add catalysts)
1	23	5.7	7.2 (new SCR)	2.0 (add catalysts)
4	83	2.5-3.5	4.8 (add catalysts)	7.1 (add catalysts)

3.3 Project Schedules

NEC estimates that it could take about 1 to 1 1/2 years to fully implement a catalyst replacement project after the plant commits to the project, depending upon the ease of obtaining sufficient catalyst. The total time includes process engineering work to firm up and fully define the relevant operating parameters. Then work is needed with the catalyst manufacturers to determine that the additional space is available in the existing SCR. Subsequently, bids would be solicited from the catalyst manufacturers and the preferred one selected. Lastly, the catalyst will be installed. However, due to the large number of expected NOx RECLAIM projects in the District, NEC feels that the time frame in obtaining catalyst could easily extend by another six months.

4. **Coke Calciner**

Facility 2 has the only coke calciner in the District and the facility did not request NEC to visit for this NOx RECLAIM project. However, NEC visited the coke calciner in 2010 during the SOx RECLAIM program. NEC's cost estimates for the scrubber to reduce SOx emissions were reported in the final non-confidential report No. SCAQMD-10-014-4. These cost results (cost factors) are also used in this report.

The coke calciner is a very challenging application. The goal of the new BARCT regulations is to achieve a 2 ppmv NOx level at 3% O_2. At present, the facility operates at 65 ppmv. NEC feels the most appropriate technology for this application would be LoTOx^{TM}. However, NEC feels that it is not possible to achieve the 2 ppmv level with this technology but rather 5 - 10 ppmv is a better BARCT target that can be achieved consistently by Facility 2. The UltraCat^{TM} technology is another one that has been considered but NEC feels that it is not proven in practice.

NEC feels that the technology as applied in a typical Belco EDV scrubber has not been proven to operate at NOx outlet levels below 10 ppmv @ 3% O_2 on coke calciners or similar applications such as FCCUs. The bulk of LoTOx™ FCCU experience is on units with regulatory limits in the range of 20 to 25 ppmv @ 3% O_2 and no design or operating data has been provided by the technology supplier for these units to indicate that operation at 2 - 5 ppmv @ 3% O_2 is possible or practical without significant changes to operating conditions, equipment, reagent usage, or process configuration. Due to this lack of data and based on our understanding of the LoTOx™ technology application in Belco's EDV scrubbers, we feel that an effluent NOx level of 2 ppmv @ 3% O_2 is an unrealistic stretch for this technology. NOx emissions limits of 5-10 ppmv @ 3% O_2 while a step out for the technology are likely to be within the capability of the current technology, as applied in the Belco process arrangement with "forseeable" process and equipment modifications. Such modifications include:

1. Additional residence time (taller scrubber, larger diameter scrubber, or a combination of these two options),
2. Complete residence time in a dry vessel instead of in the bottom of the EDV scrubber (two vessels instead of one),
3. Higher ozone usage, or
4. Multiple stage ozone injection.

To obtain a capital cost estimate for using the LoTOX™ application on the calciner it was necessary to apply a Process Development Allowance (PDA) to the cost of the technology to account for the unknown items noted above. At a minimum, NEC recommends including PDA in the cost estimate to cover a doubling of the system reaction volume (in the base case, the reaction volume is approximately 60% of the system volume) and a doubling of the ozone supply (including three ozone generators instead of two in the system supply and doubling ozone operating costs). With these additions we feel the cost for the LoTOx™ application will be consistent with a NOx emissions level of 5-10 ppmv dry @ 3% O_2.

One of the important conclusions of the NEC 2010 SOx RECLAIM report is that calciner space availability is very tight, and most of the equipment would have to be built elevated above the road used for coke loading/unloading access. The additional costs for installation of the LoTOx^{TM} scrubber at the calciner will need to be included in capital cost for this application. The prior capital cost developed by district staff does not appear to include this factor.

4.1 Costs Summary

NEC's experience with LoTOx^{TM} vendor's TIC estimates is that they are accurate for installation of the major equipment components in a "prepared" location but do not include costs for civil work, piping, instrumentation, insulation, equipment access, large cranes, DCS configuration, power supply, utilities upgrades or additions, etc. In NEC's 2010 SOx report, it shows an increased total investment by a factor of 3.44 over the cost reported by the consultant using information supplied by the LoTOx^{TM} vendor. While some of the increase was necessitated by the elevated location of the equipment, most was because of inaccuracy in determining project indirect costs.

The following table shows the Total Investment Cost (TIC) and Present Worth Value (PWV) for the coke calciner. The TIC includes all material, labor, engineering, construction, and infrastructure costs for a project and is based on the plant startup in the present year (2014). The PWV is a SCAQMD defined terminology described in the following equation assuming 4% interest rate and 25 years operation.

$$PWV = TIC + (15.62 \times AC)$$

where:

TIC is the Total Installed Costs, $

AC is the Annual Operating Costs, $

4.2 PWV Comparison

The following table compares the PWV values calculated by SCAQMD to those of NEC for the coke calciner.

Item	LoTOx^{TM} Vendor ($ M)	AQMD's Estimate ($ M)	NEC Estimate Based on 2010 SOx report ($ M)
M+L	4.8	-	4.8
PDA	-	-	1.7
Adjusted M+L	4.8	-	6.5
TIC	6.25	9.375	22.4
AC	0.5443	0.816	1.1
PWV		22.1	39.5

The following is the basis for the above table.

- Based on NEC experience, Belco TIC estimate is equivalent to M+L multiplied by 1.3. NEC's estimate is based on applying a PDA of 1.35 to the Belco's LoTOx^{TM} M+L.
- The 2010 SOx report uses a factor of 3.44 times the vendor's TIC to obtain NEC's TIC estimate.
- Increased utility costs are the result of the additional electricity and oxygen supply necessitated by additional ozone consumption. Additionally, the Belco estimate is for 33.3 lb NOx/hr in the flue gas. However, Facility 2 has recently advised NEC and SCAQMD that the current NOx level is 55 lb/hr (0.66 tpd), almost 3 times higher than its 2011 emissions at 2005 BARCT level, which further increases the utility cost.

4.3 Project Schedules

NEC estimates that it could take about 2 years to fully implement a LoTOx^{TM} project after the plant commits to the project. This time includes process engineering work to firm up and fully define the relevant operating parameters, the preliminary plant layout, and the preparation of a process design package. The next phase called Detailed Engineering would consist of obtaining the LoTOx^{TM} manufacturer's quote and design, and completing all the detailed engineering including other equipment, infrastructure, and all purchasing. Finally, construction and start-up would occur. However, due to the large number of expected NOx RECLAIM projects in the District, NEC feels that this time frame could easily extend to 3 years as engineering and construction resources will be very difficult to obtain.

5. Sulfur Recovery Units and Tail Gas Treatment Units

The effluent gas from the sulfur recovery and tail gas treatment units (SRU/TGTU) flows to a thermal oxidizer (incinerator), where the residue H_2S in the tail gas is oxidized to SO_2 before being vented to the atmosphere. NEC visited three incinerators in the SCAQMD: one at Paramount and two at Tesoro LAR. Three technologies that SCAQMD considered feasible for this application are Selective Catalytic Reduction (SCR), LoTOx^{TM}, and Know-NOx^{TM}.

The goal of the new BARCT regulations is to achieve a 2 ppmv NOx level at 3% O_2. NEC feels that the only major control technology that can achieve the 2 ppmv NOx level in this application is Selective Catalytic Reduction (SCR).

NEC feels that the LoTOx^{TM} technology as applied in a typical Belco EDV scrubber has not been proven to operate at NOx outlet levels below 10 ppmv @ 3% O_2 on incinerators or FCCUs. The bulk of LoTOx™ FCCU experience is on units with regulatory limits in the range of 20 to 25 ppmv @ 3% O_2 and no design or operating data has been provided by the technology supplier for these units to indicate that operation at 2 - 5 ppmv @ 3% O_2 is possible or practical without significant changes to operating conditions, equipment, reagent usage, or process configuration. Due to this lack of data and based on our understanding of the LoTOx™ technology application in Belco's EDV scrubbers, we feel that an effluent NOx level of 2 ppmv @ 3% O_2 is an unrealistic stretch for this technology. NEC also feels that the Know-NOx technology is unproven, so it cannot meet the 2 ppmv NOx level. It has only been installed at two locations in the US and has not yet been tested in any refinery applications to date.

The inlet NOx concentrations for the units being evaluated range from 6.6 ppmv for Facility 6 Device ID 952, to 46 ppmv with the average concentration being about 30 ppmv. This is considerably lower than the 60 ppmv experience in typical heaters and boilers. NEC feels that for the single application at 6.6 ppmv, a two-bed SCR arrangement is feasible to meet the 2 ppmv NOx level. However, for the other six units, NEC recommends a three-bed arrangement. The SCR vendors feel that the low levels of SO_2 in the tail gas after incineration are at very low levels so they will not impact the SCR performance.

The incinerators for Facilities 6 and 8, and both at Facility 1, are operating with flue gases at 1,080 ^{o}F to 1,300 ^{o}F. Since this is too hot for the proper operation of an SCR, the flue gases must be cooled down to 650 ^{o}F. Therefore, these units require a waste heat boiler to cool the flue gases while generating high pressure steam. Since these units would provide steam to the refineries, they will obtain a credit for the actual steam produced. While this credit could possibly be as high as 0.5 MM$ per year, we have not taken advantage of this in any of the economics. This requires more discussions with the individual refineries regarding the capacity utilization of the incinerators and the actual utility costs and savings that could realized.

5.1 Costs Summary

The following table presents the Total Investment Cost (TIC) and Present Worth Value (PWV) for the SRU/TGTU. The TIC includes all material, labor, engineering, construction, and infrastructure costs for a project and is based on the plant startup in the present year (2014). The PWV is a SCAQMD defined terminology described in the following equation assuming 4% interest rate and 25 years SCR life with 5 years catalyst replacement cycle. Note that PWV does not include any credit for heat recovered in the waste heat boiler.

$$PWV = TIC + (15.62 \times AC) + (2.52 \times CR)$$

where:

TIC is the Total Installed Costs, $
AC is the Annual Operating Costs, $
CR is the Catalyst Replacement Costs, $

Fac. ID	Device ID	Max Rating, MMBtu/hr	Flue Gas Flow, dscfm	Temp, F	NOx, ppmv	TIC, MM$	PWV, MM$
6	952	100	34,640	1,080	6.57	19.6	22.2
5	911/913	30/25	12,500	515	29	8.3	9.5
5	927/929	30/25	12,500	570	28	8.5	9.6
5	955/957	58/41	14,500	520	29.8	8.9	10.3
1	910	45	32,167	1,260	28	22.0	25.5
1	2413	40	27,167	1,292	18	10.2	23.2
8	294	28	23,284	-	32	16.7	19.3

The following is the basis of the above table.

- The base SCR box size was prorated from the FCCU SCR budget type size obtained from the prominent SCR vendor. The prorated cross section area was calculated to provide a 10 ft/sec velocity. Note that the SCRs proposed for this application by the SCR vendor were sized for a velocity of about 10 ft/sec for the smaller ones. However, the velocity was about 50 ft/sec for the two larger ones, Facility 6 and 8. It appears there was confusion about the actual flow rate for the larger units.

- Process calculations were done for incinerators to determine the actual flue gas rate at the reported stack temperatures and moisture content. SCR box costs were then prorated from the FCCU budget type SCR box quote based on actual volumetric flow rates. This calculation is based on 0.6 power law function.
- The same material costs for the FCCU SCR box provided by Manufacturer C (of the FCCU SCRs) were used and adjusted to the NEC's sulfur recovery/tail gas incinerator design basis of three beds. The initial catalyst supply cost ($/volume) was also provided by Manufacturer C (of the FCCU SCRs) and is also included as a material cost.
- Based on NEC's extensive experience, these costs were then increased by a bid conditioning factor of 1.35 to account for manufacturer cost bias and upgrading to plant standards.
- Waste heat boiler TIC cost were estimated at about 4 MM$ for Device 910 at Facility 1. Other units are prorated on a 0.6 power function.
- Costs for ammonia injection facilities and a skid to vaporize 29% ammonia solution are included.
- Costs for an 11,000 gallon aqueous ammonia storage tank are included, based on a 7,000 gallon tank truck delivery as advised by the prominent Southern California ammonia supplier.
- A new CEMS system is installed to meet the new requirement to measure NOx at 2 ppmv level.
- Infrastructure costs and contingency were included in the TIC factor that was applied. This factor is based on NEC's project experience and accounts for the average difficulty of installing new facilities in an existing large refinery operating unit.
- The table represents an installation of average difficulty within the District of constructing the new SCR.
- Maintenance is 0.35% of TIC.
- Ammonia cost is $475 /ton for 29% aqueous NH_3 solution. Actual cost is calculated based on the actual NOx level for each individual incinerator.

- Catalyst cost varies between 0.32 MM$ for Facility 8 to 0.1 MM$ for the small incinerators.
- Miscellaneous costs for ammonia skid are included.

5.2 Project Schedules

NEC estimates that it could take about 2 years to fully implement an incinerator SCR project after the plant commits to the project. This time includes process engineering work to firm up and fully define the relevant operating parameters, the preliminary plant layout, and the preparation of a process design package. The next phase called Detailed Engineering would consist of obtaining SCR manufacturer's bids, selecting the preferred manufacturer, and completing all the detailed engineering, including other equipment, infrastructure, and all purchasing. Finally, construction and start-up would occur. However, due to the large number of expected NOx RECLAIM projects in the District, NEC feels that this time frame could easily extend to 3 years.