Evaluation of Cost Data

South Coast Air Quality Management District (SCAQMD)

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Document No.: 19-9009-017
Project No.: AQMD-19-9009
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Date: 6/14/2021
Revision: 2

1. Introduction

The SCAQMD (South Coast Air Quality Management District) has recently received feedback from several refineries in the Los Angeles area on the cost to implement Best Available Retrofit Control Technologies (BARCT) for stationary emitters of nitrogen oxides (NOx). The SCAQMD is looking for an independent review of this data to determine whether the costs submitted are reasonable, realistic, and justified for NOx control equipment installations. SCAQMD would like NEC to also recommend additional factors or considerations that may potentially impact the costs. Recommendations may also include actions to exclude cost data that do not or should not pertain to the requirements of Proposed Rule (PR) 1109.1.

2. Findings and Conclusions

TIC estimates for two sets of modifications were received, Ultra Low NOx Burner (ULNB) upgrades and SCR retrofits/upgrades.

20 TIC estimates were provided from 3 refineries for ULNB upgrades on various heaters and boilers in the district. When these numbers were compared against “Typical” installation costs that were generated for ULNB upgrades in the district there are five (5) outlier points. The other 15 TIC estimates are within the expected range of the typical costs for ULNB upgrades in the district.

3 of the 5 units with a higher-than-typical TIC estimate were associated with coker heaters and 2 of the 5 units were associated with boilers. Work scope was not provided for TIC estimates on these 5 outliers, it was not possible to identify what makes these isolated points higher than the rest of the data set. In our experience we have seen cases where the complexity factor is high for these type of units. Coker heaters typically have multiple fireboxes, each with independent fuel gas controls and a large number of small burners increasing the complexity and cost for these types of units as compared with typical refinery heaters. ULNB installations on boilers, which do not have low NOx features (raw gas burners, air preheaters, no flue gas recirculation, etc.) typically require extensive modifications and resultant high installation costs.

During the early phase of PR 1109.1, 49 TIC estimates were obtained from 7 refineries in the district for SCR retrofit and upgrade projects on heaters and boilers > 40 MMBtu/h. In 2021 a total of 62 revised TIC estimates were received on the same units, along with other units that were not previously included. The TIC estimates between the first submission and second submission for all but two heaters in the district increased by a factor of 1.05 to 2.4 times their original estimate. From limited information that was provided by the refineries, the increase in TIC has been attributed to improved scope definition that was previously covered by contingency during the early phases of conceptual engineering. A range of complexity factors such as space constraints; civil/structural upgrades; electrical infrastructure/fan upgrades; expansion of the NH_3 vaporization system; instrumentation/ controls upgrades; and heater coil modifications to accommodate a retrofit SCR are all items that can have an impact on the “typical” TIC for individual units. NEC did not perform project-specific screening during the earlier phases of work and we would expect the cost numbers prepared would be revised upward once a cursory, site and unit specific estimate was developed.

While there is limited information to make a definitive assessment of scope definition versus TIC, it is NEC’s opinion that the TIC estimates provided in 2021 do not appear unreasonable when complexity factors are turned into defined scope during the latter phases of engineering. At least half of the data set obtained in 2021 still falls within the “expected” TIC range for SCR retrofits on heaters and boilers. From limited information provided in the responses from the refineries there does not appear to be extraneous scope items included in the TIC estimates.

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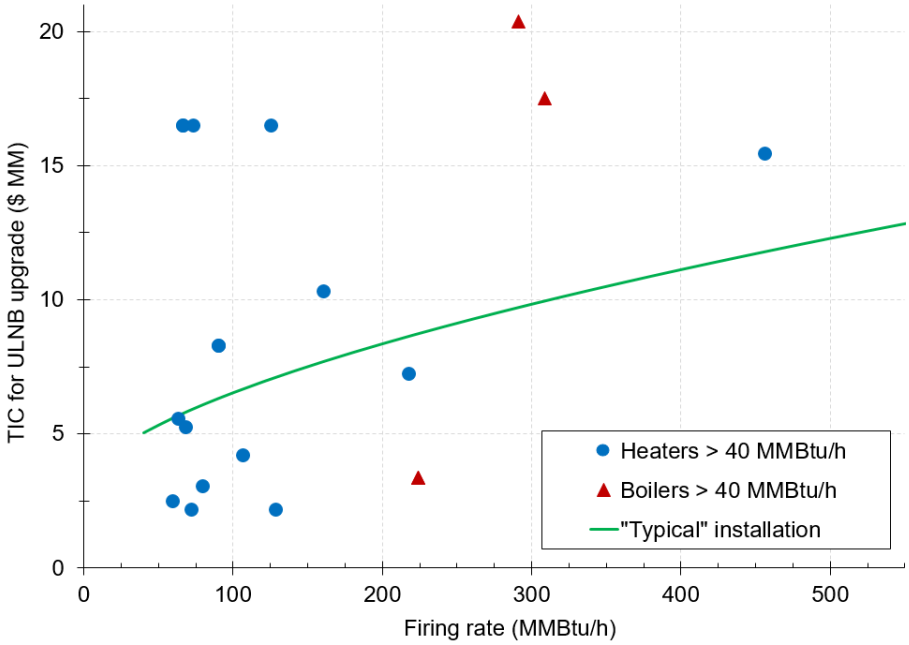
3. Review of Ultra Low NOx Burner (ULNB) Upgrade Costs

Three refineries in the district provided a breakdown of costs based on ULNB upgrades. The data for heaters and boilers > 40 MMBtu/h is presented in Figure 1.

Figure 1: TIC cost for ULNB upgrades on heaters and boilers > 40 MMBtu/h



The green line in Figure 1 represents a “typical” installation where the scope of work includes:

- New ULNB burners,
- Heater floor modifications,
- Minor automation updates,
- Fuel gas piping upgrades including filters/coalescers (per API recommendations for ULNBs).

Representative installations from NEC’s experience list were used to generate a TIC and prorated costs were obtained from a 0.6 power law function based on firing rate. If a CEMS is required then $0.5 MM should be added to the curve. The three points in Figure 1 at $16.5 MM for heaters < 200 MMBtu/h is high for a typical ULNB upgrade project. Without scope definition it is difficult to compare these TICs against “typical” ULNB upgrades. It is worth noting these high estimates are for coker heaters. A coker heater can have:

- Multiple fireboxes, each with independent fuel gas controls,
- A large number of small burners.

This can increase the complexity factor over a “typical” heater upgrade. However, NEC cannot say with certainty what is driving these particular TIC estimates without scope definition, particularly given another refinery provided a TIC estimate that is almost $10 MM lower for ULNB upgrades on a large coking heater.

Other outlying data points on Figure 1 include boilers in the 300 MMBtu/h range. When upgrading the burners on a boiler there may be additional considerations including:

- Modifications to the existing heat transfer coil,
- Modifications to the Flue Gas Recirculation (FGR) system

Without scope definition it is difficult to ascertain if a complexity factor should be applied to these units.

Recent discussions with Clearsign™ indicate the cost of the CORE burner, considered a leading candidate in the next generation of emerging ULNB technologies, will run in the $100,000+ range per burner. Current ULNBs cost around one-tenth of this per burner. If the Clearsign™ CORE will become the basis for burner upgrades in future projects then NEC would expect the "Typical" installation curve shown in Figure 1 to move significantly higher.

The cost of burner upgrades for non-heater/non-boiler units can vary. These are specialized burners and in some cases the combustion chamber itself may need to be modified to accommodate upgraded burners, which would increase the complexity factor for such installations. Without scope definition it is hard to speculate on factors that impact the TIC estimate. Feedback from John Zink indicates burner upgrades for sulfuric acid plants and thermal oxidizers can run upward of $5 MM depending on the application and the configuration of the existing equipment.[1] Data from two different refineries for SRU thermal oxidizers are in the $6-8 MM range, which is reasonable based on the estimate from John Zink.

[1] NEC document 19-9009-016 "NOx BARCT Analysis Review", Rev. 4, December 4, 2020

4. Review of SCR Costs for Heaters and Boilers

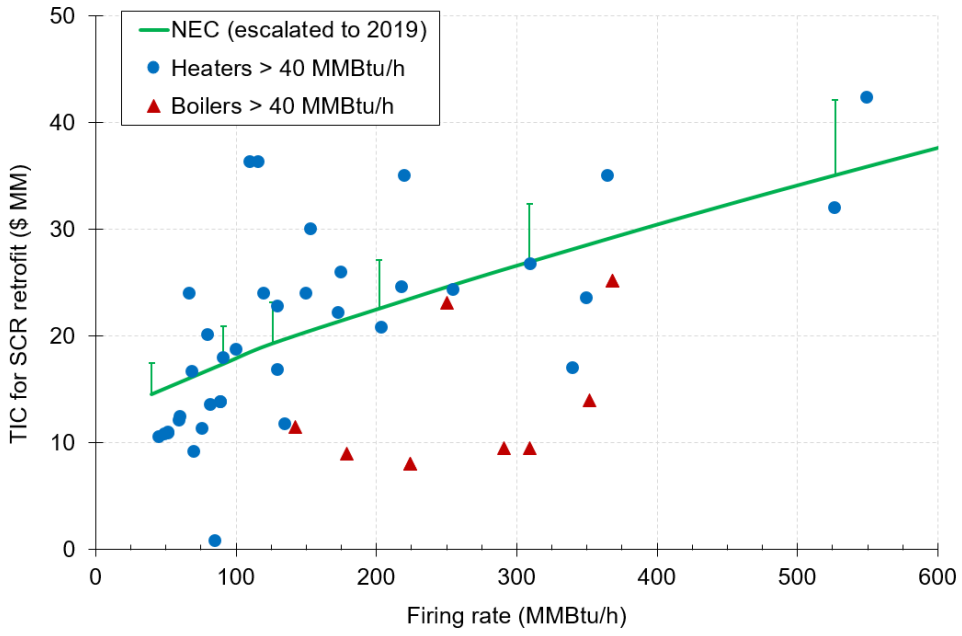
Refineries in the district have submitted two rounds of TIC estimates for SCR retrofits. The first round of refinery TIC estimates was generated during the early phase of PR 1109.1. Figure 2 compares the first round of TIC estimates against NEC's estimate generated during the 2014 NOx RECLAIM BARCT feasibility study for SCR units on heaters and boilers in the district.[2] The data from 2014, escalated through December 2019, is plotted in Figure 2 against the first round of TIC estimates received from the refineries.

Figure 2 shows the escalated NEC estimate roughly passes through the middle of the data obtained from refineries for the first submission of TIC estimates. The NEC estimate from 2014 was based on:

- A three bed catalyst system with superficial gas velocity = 10 ft/s,
- Material costs including catalyst were obtained from a reputable SCR vendor,
- Various infrastructure costs were factored for a "typical" facility.

Error bars on the NEC estimate accounts for a 20% allowance on heaters and boilers where the SCR is difficult to install (i.e. represents a complexity factor). From the 49 TIC estimates that were obtained, 5 appear significantly higher than NECs escalated estimate.

Figure 2: First submission of TIC estimates for SCR retrofits on heaters and boilers > 40 MMBtu/h



The second round of TIC estimates, which firmed up costs for retrofits to several heaters and boilers from refineries in the district, was received late 2020/early 2021. NECs data from November 2014[2] was escalated to February 2021 and is plotted against TIC estimates obtained from the refineries during the second round of submissions,

[2] NEC document 14-045-4 "SCAQMD NOx RECLAIM – BARCT Feasibility and Analysis Review", November 26, 2014

see Figure 3. Figure 3 shows the escalated NEC TIC is now at the lower end of the data obtained from refineries. From the 62 TIC estimates that were obtained, 15 now appear significantly higher than NECs escalated estimate.

Figure 3: Second submission of TIC estimates for SCR retrofits on heaters and boilers > 40 MMBtu/h

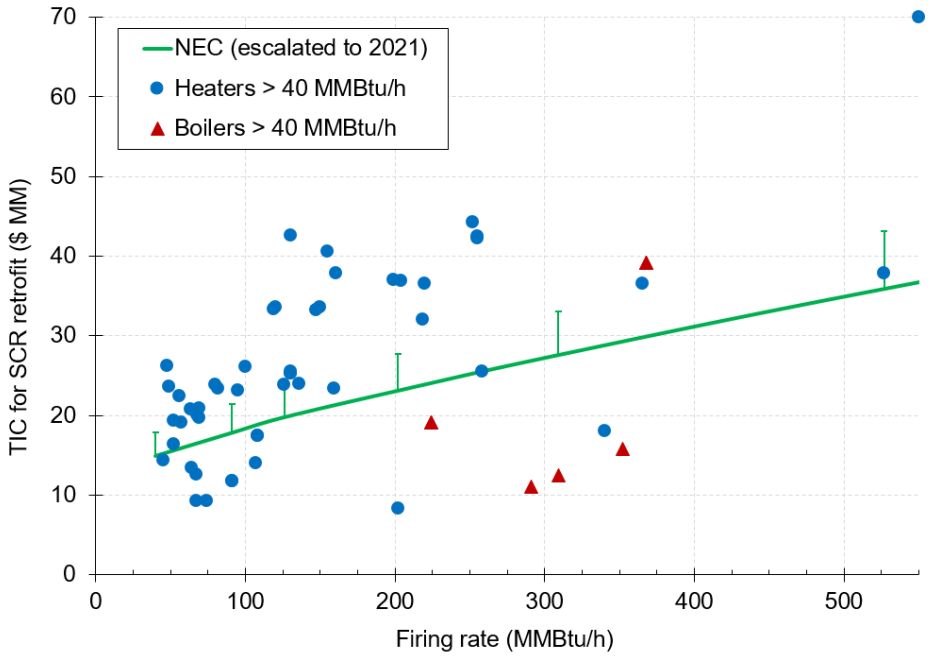
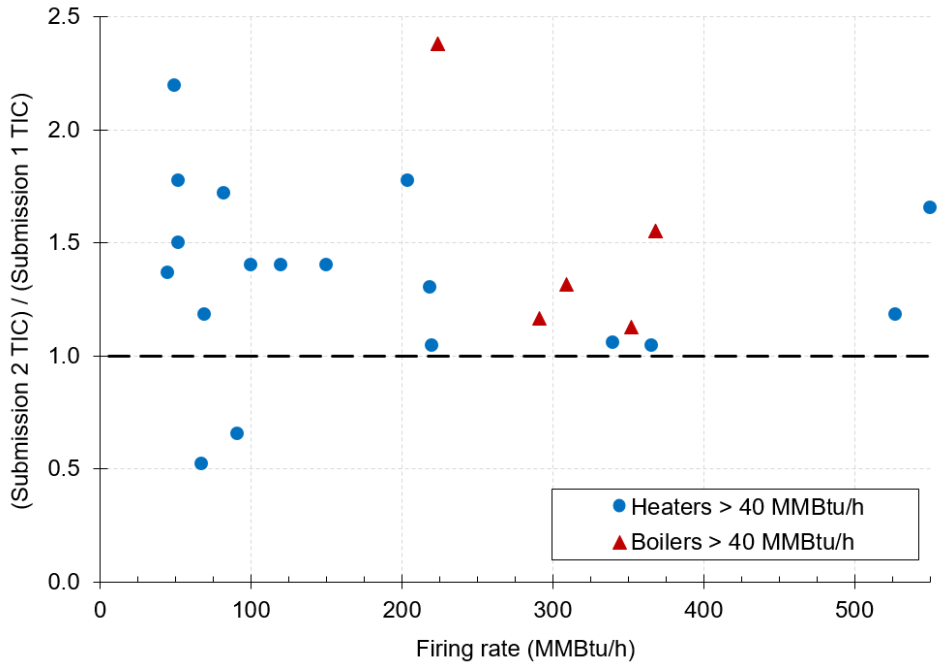


Figure 4 compares the ratio of second submission TIC estimate divided by the first submission TIC estimate for heaters and boilers where both were available. While two heaters in the district had a lower price in the second submission, the majority of units all went through a TIC increase on the second submission.

An increase in the TIC is not unusual as project scope becomes more clearly defined through the latter stages of engineering. During conceptual engineering phases it is typical for the contingency on a TIC estimate to be in the +50% range to address any complexity factors that have not yet been identified. As detailed engineering progresses the uncertainty associated with complexity factor is replaced with defined scope that can be estimated. In many cases it is not easy to address complexity factor until engineering is performed. Items related to the complexity factor that impact a TIC estimate include:

- Footprint required for new equipment and the extent of civil/structural upgrades required.
- Space constraints (i.e. Where will the equipment be located? What needs to be done to get to and from this location?).
- Extent of electrical infrastructure/fan upgrades required (i.e. does new SCR capacity impact pressure drop?)
- Will an expansion of the NH_3 vaporization system be required?
- Is there a need for CEMS and other instrumentation/control upgrades?
- Will the upstream heater require a modification? (i.e. replace/upgrade heat transfer coils to allow the SCR to operate within the optimum temperature range of 650 to 750°F for maximum NOx removal)

Figure 4: Ratio of first-to-second submission TIC estimates where both were available for heaters and boilers



Feedback from several refineries indicate the increase in TIC was attributed to scope definition associated with complexity factors. A few select examples are provided below.

Refinery 1 provided a second round TIC estimate for a particular heater at $55 MM when project scope identified new electrical infrastructure, new structural foundations and a new NH_3 vaporizer were required. The first round submission for TIC estimate was $37 MM.

Refinery 2 commented that two separate SCRs would be required on two boilers that share a common stack. These boilers must provide the refinery with baseload steam demand that prevents taking both boilers out of service at the same time for a common SCR upgrade. In this case separate SCRs would be required although a common SCR would be preferred.

Refinery 2 provided feedback that several units were space constrained and TIC increased by a factor of 1.7 to 1.8 times the original conceptual phase TIC estimate once additional engineering was performed.

Refinery 5 provided a second round TIC estimate for a heater at $15 MM at an accuracy level of +/-10%, this was previously estimated at $12.5 MM.

While there were several TIC estimates provided for SCRs on the feed heater to the FCCU (these were lumped into the heaters and boilers category), there was limited feedback on SCR costs for FCCU regenerator flue gas NOx control. Refinery 1 provided a range of TIC estimates for upgrading an existing SCR on the flue gas stream leaving the FCCU regenerator to get from 8 ppmv NOx to 5 ppmv NOx. One estimate calls out infrastructure

modifications to the SCR for a TIC of $50 MM. Escalating NECs TIC estimate for FCCU SCR units from 2014 to 2021 puts this modification in the $44 MM range.

The TIC estimate from Refinery 7 includes NOx, SOx and PM emission reductions as the basis for a Wet Gas Scrubber (WGS) retrofit on the FCCU regenerator flue gas line. If NOx reduction alone is the requirement then a WGS retrofit would not be the preferred option. If an existing WGS is present then LoTOx can be added in front of this unit to convert NOx to N_2O_5, the N_2O_5 can then be captured and removed in the existing WGS. The location for installing a LoTOx unit and its associated infrastructure, along with minor modifications to the WGS should be considered. If a WGS is not present then SCR would be the preferred technology over LoTOx provided SOx and PM are separately controlled.

From the responses that were received, extraneous scope does not appear to be included in the TIC estimates for a retrofit. However, this is a general statement and without a detailed breakdown of the scope for individual projects is hard to justify.

The data presented thus far is for a retrofit of an existing unit. A few isolated data points were provided from refineries that capture upgrade costs for an SCR, see Figure 5.

Apart from one data point provided at ~150 MMBtu/h the TIC falls within the expected range of a catalyst upgrade. Scope for the upgrades on the outlier at ~150 MMBtu/h is not defined but may involve additional factors over and above a catalyst upgrade, see the bullet points called out above for complexity factor.

Figure 5: TIC estimates for SCR upgrades on heaters and boilers > 40 MMBtu/h