



Meeting Current Emissions Limits With Multiple Retrofit Solutions

Authors: John M. Boyle, PhD., Fuel Tech, Inc., Andrew Rankin, Drax Power Station

ABSTRACT

In 2014, Fuel Tech completed full-scale demonstrations of Advanced Selective Non-Catalytic Reduction (ASNCR) systems on two large utility boilers (>600MW) firing Coal and Biomass. The systems utilized the latest flexible injection technology and are controlled with a balanced algorithm including unit load, a full grid of continuous furnace temperatures and the plant continuous emissions monitoring system (CEMS).

Early this year, Fuel Tech and Doosan conducted another demonstration of ASNCR on a 105Mw unit in the UK firing a Russian coal blend. This demonstration provided encouraging results and showed the value of low-capital high-performance NO_x reduction on an aging asset. Additional work is planned for the remainder of the year at this facility, including further testing and application of ASNCR on a second unit.

Significantly, the commercial installation and startup of five large (645Mw) ASNCR systems is nearing completion at Drax Station in the UK. Unit 4 at Drax Station fires a blend of coals and controls the emission of NO_x using a suite of technologies including low-NO_x burners (LNB), over-fired air (OFA), combustion optimization software, and urea-based Advanced SNCR.

Fuel Tech has more installed SNCR applications than any other technology supplier, with more than 590 units firing all types of fossil, biomass, and industrial fuels. These systems are currently installed and operating on units ranging in size from small industrial furnaces to some of the largest utility boilers in the world.

Over the last 16 years, Fuel Tech has completed more than 50 installations on units larger than 400MW, where the majority of these units are larger than 600MW. Large units pose a particularly difficult challenge to SNCR emission control systems, as these modern units generally have higher furnace exit gas temperatures, incorporate low-NO_x burners, over-fired air and have very low baseline NO_x emissions. Each of these factors can potentially limit the effectiveness of SNCR.

Fuel Tech uses the most advanced computational fluid dynamics (CFD) and chemical kinetics modeling to design sophisticated injection strategies that anticipate varying load and fuel conditions in the furnace. The analysis is translated into engineering systems that incorporate numerous injector types to deliver the reagent as effectively as possible. The target injection zone varies based on temperature, NO_x baseline, CO concentration and furnace residence time. CFD modeling is required to accurately predict these shifts in the target region.



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INTRODUCTION

Control of Nitrogen Oxide Emissions

The emission of nitrogen oxides (NO_x) is a well-known problem for air quality, leading to the formation of tropospheric ozone and acid rain as well as adversely affecting visibility. Nitrogen oxides are formed in combustion with air at high temperature and are a particular regulatory concern for many power producers burning fossil fuels. The regulation of NO_x emissions varies significantly across the globe and the required degree of control is often dependent on the source of the emissions, including the manner of combustion and the specific fuel utilized. Significant reductions are required for most utility furnaces in developed countries.

NO_x control strategies include efforts to inhibit NO_x formation such as fuel switching, combustion modifications, low- NO_x burners (LNB) and combustion staging with over-fired air (OFA). Post-combustion NO_x control technologies are also utilized, such as selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR) of the nitrogen oxides through reaction with amines such as ammonia and urea. Although not all of these technologies are applicable to each utility furnace, it is often possible to create useful and efficient combinations to enhance performance and provide the most cost-effective regulatory compliance.

Fuel Tech Inc. has 30 years of experience applying each of these NO_x control technologies to industrial and utility furnaces. This experience is important and relevant to commercial applications as each custom NO_x control strategy requires interaction with any existing strategies in place at the site. For example, it is very common to install post-combustion NO_x control to furnaces that have previously been equipped with some level of combustion control. The first-hand experience that exists within the Fuel Tech groups responsible for LNB and OFA design reinforce the strengths of the post-combustion control design effort. It is often useful, in fact, to suggest operational enhancements to the current controls that work synergistically with post-combustion processes.

Staged-combustion NO_x control technologies, like LNB and OFA, reduce the formation of NO_x by limiting the availability of excess oxygen in the high-temperature combustion zone where nitrogen oxidation occurs. Complete fuel oxidation is accomplished with burner swirl of additional combustion air and through the introduction of over-fired air. Combustion staging is limited by an increase in the unburned carbon in the ash (for solid fuels), increased carbon monoxide (CO) concentrations, higher furnace exit gas temperature and a decrease in furnace efficiency.



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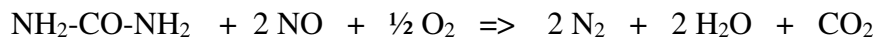
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Post-Combustion NO_x Control

Post-combustion NO_x control is generally utilized when combustion staging is not sufficient to provide the required emission target. Selective catalytic reduction (SCR) utilizes a catalyst bed to promote the reduction of NO_x by reaction with an amine, such as ammonia or urea. The catalyst bed is very effective at providing NO_x reduction and is used routinely on large units where the gas temperature and fuel compatibility metrics have been satisfied.

SCR requires the construction of a reactor vessel, which is often very expensive. This capital expense needs to be spread over the remaining years of unit operation, however, this cannot be justified in many cases. The high utilization of the chemical reagent in an SCR, and often-higher NO_x reduction capability, provides some payback for this expense. SCR reactors, especially full-scale reactors capable of NO_x reductions beyond 60%, are not always a feasible solution. This is particularly true in the retrofit market.

Selective Non-Catalytic Reduction (SNCR) of NO_x occurs in the furnace, utilizing the hot gas environment of the furnace to drive the desired reduction chemistry. An aqueous solution of urea is the most common reagent, especially for large furnaces. Urea (NH₂-CO-NH₂) reacts with NO_x in the hot post-combustion gases to produce nitrogen gas (N₂), carbon dioxide (CO₂) and water (H₂O), all typical combustion byproducts.



SNCR generally operates at a chemical utilization of about 30%, on a molar basis, although this is highly dependent on the furnaces conditions. Most of the unutilized urea is simply combusted to form nitrogen gas, water and carbon dioxide. At very high temperatures, some of the urea-bound nitrogen may be oxidized to form NO and so there is an upper temperature limit for effective control. In addition, at relatively low flue gas temperatures, the urea may be converted to ammonia gas and some portion may remain unreacted as ammonia slip at the boiler exit. This sets a lower temperature limit.

The resulting temperature window for effective SNCR injection is a key process design parameter for injection design and performance predictions. Successful applications of SNCR injection require a thorough understanding of the temperature, residence time and gas concentrations in the furnace. In addition, it is vitally important that this injection strategy be flexible to provide NO_x control over a wide variety of load conditions, mill configurations, and fuel selections.

The most sophisticated applications have been designated as Advanced-SNCR systems, utilizing acoustic or laser-based means of producing near real-time maps of furnace conditions that are then used to control the location and manner of injection for NO_x control. The



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advanced SNCR system also contains logic to respond to ammonia CEMS and to predict future furnace behavior by monitoring current furnace transients.

BACKGROUND

Scale-up of SNCR to Large Furnaces (>400MWg)

Fuel Tech has been responding to the unique SNCR needs of very large utility furnaces for more than 20 years, since our first large-furnace application in 1993. Regulations in the United States drove application of SNCR on large units in the late 1990s, including a showcase demonstration utilizing six multiple nozzle lances in 1999 at the 620MW Cardinal Station Unit #1. This wall-fired large furnace was equipped with low- NO_x burners and had recently been optimized to control CO and NO_x while burning high sulfur coal.

The particular challenges of SNCR scale-up to very large furnaces are not new. As compared to the earlier work on units smaller than 400MW, these larger furnaces often have lower NO_x baselines, higher furnace exit gas temperature (FEGT), and increased convective pass concentrations of carbon monoxide. Each of these attributes affects the design of an effective SNCR system.

The applicable temperature window for SNCR injection is defined by the chemical kinetics of the reduction reactions and by the conditions in the furnace. Low NO_x baselines effectively push the temperature window to cooler regions near the convective pass. In addition, an increased CO concentration also shifts the temperature window in the same direction, toward cooler gas conditions. Finally, these larger modern units are designed for higher steam temperatures, and so require a higher FEGT. These characteristics of large furnaces do not prohibit effective SNCR treatment, but they do require a more sophisticated approach to control and injection.

For example, Figure 1 illustrates the target temperature window for an application completed at 620MW where the CO concentration in the convective pass is 500ppm. It is reasonable to assume that the CO will experience significant variation both spatially and transiently for a furnace with combustion staging. The target temperature window may shift dramatically and an effective SNCR system must be equipped to sense this difference and respond appropriately.

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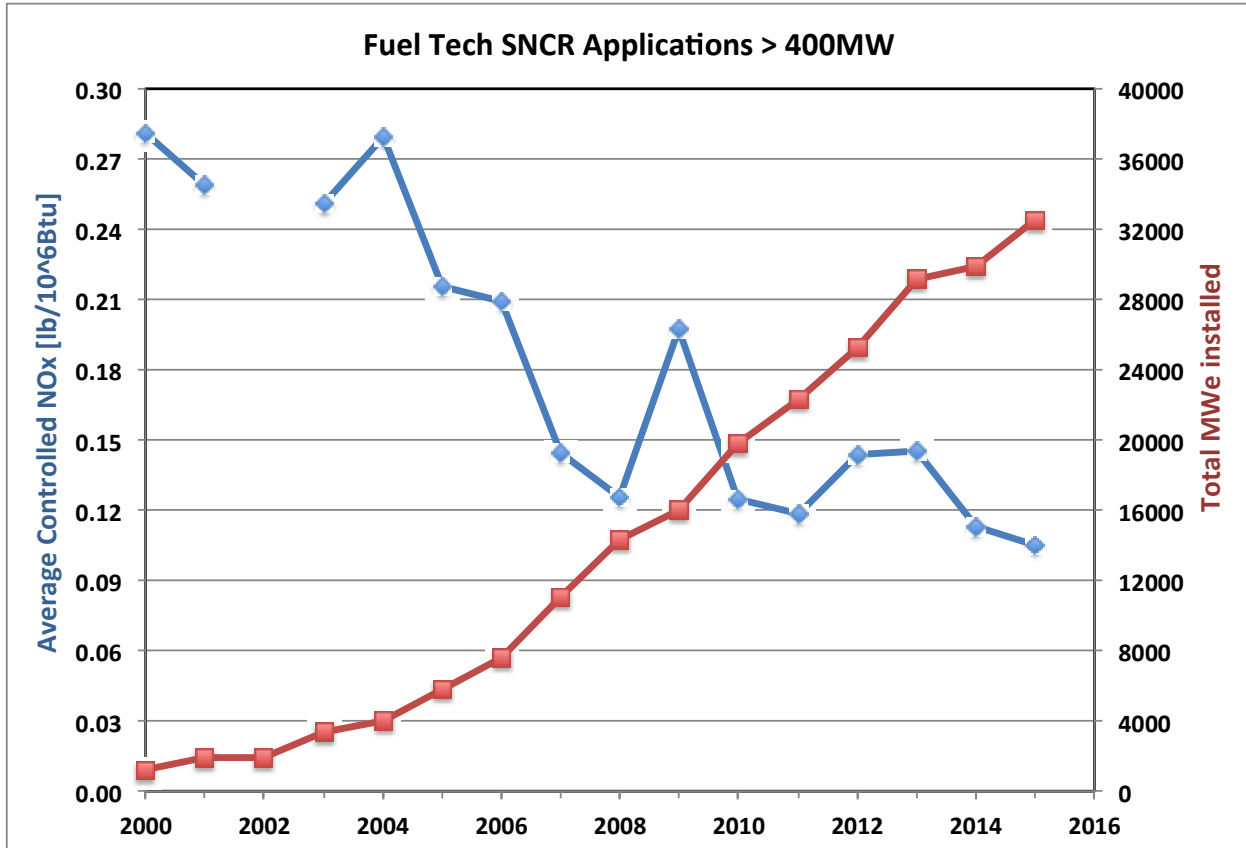


Figure 2 Fifteen years of large-furnace SNCR activity at Fuel Tech

Over this time, Fuel Tech has advanced the state-of-the-art to maintain an average NO_x reduction of 30% on large units, even as the baselines have decreased with combustion staging. These large units make up about 10% of Fuel Tech’s installed base.

Large Utility Furnace Example - 2014

The most effective manner in which to illustrate the effectiveness of SNCR on large utility furnaces is through example. In this case, there were two apparently identical furnaces that were retrofit with SNCR utilizing Fuel Tech’s Multiple Nozzle Lance (MNL), see Figure 3, an innovation for the large utility market that has been in commercial use for more than 15 years.

The installation was on two identical 620MWg Riley turbo-furnace units burning Powder River Basin subbituminous coal (PRB). The baseline for both units averaged 0.23lb/10⁶Btu. The target temperature windows on the two furnaces were different as the outage schedules left one furnace more severely coated with slag. This furnace and was operating with a higher furnace

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exit gas temperature and higher furnace CO concentrations.



Figure 3 Multiple Nozzle Lance (MNL) injector is used for convective pass SNCR injection

Although wall injectors were appropriate for the cooler furnace, the Multiple Nozzle Lance was required for the warmer furnace. This was, of course, expected to change with time in operation and the planned outage schedule for cleaning.

The Fuel Tech MNL is water-cooled and manipulated with a “rack and pinion” retract mechanism similar to what is commonly used for soot blowing lances. The resulting spray patterns can be controlled to carefully provide extremely effective chemical injection while minimizing any risk to the convective pass tubes. Although the MNLs are more expensive to fabricate and install than typical wall injectors, they are sometimes the most effective solution for NO_x control on large furnaces and help to keep dilution water flow rates as low as possible.

The use of both wall-injection levels and MNLs were optimized on both units and the resulting performance was 36% reduction on both units (< 0.15lb/10⁶Btu), while maintaining ammonia slip limits. The SNCR treatment varies between the wall injectors and MNLs in a manner consistent with furnace conditions and the unit load.



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PROJECT APPROACH

Fuel Tech's most sophisticated SNCR suite of technologies is the Advanced-SNCR system. Advanced-SNCR utilizes acoustic or laser-based means of producing near real-time maps of furnace conditions that are then used to control the location and manner of injection for NO_x control. In some cases the temperature mapping is the primary control signal. In other cases, the temperature mapping is used to select injectors within an injection zone for special operations.

Standard Fuel Tech SNCR systems have logic designed to control operations based on unit load, NO_x CEMS, upper furnace temperature and ammonia slip data. The Advanced system provides additional flexibility, utilizing our proprietary CFD and CKM model technology in concert with near real-time furnace contour maps to modify individual injection selection or treatment rates.

SNCR "performance" can be measured in many ways, and all are important to varying degrees. Certainly the achievable NO_x reduction and ammonia slip are the foremost measures of performance. The chemical utilization is also critical to the operating cost of the system, as are the dilution water and injection air. Finally the ability of the system to operate dynamically and effectively over a wide load range is also significant.

Fuel Tech's first application and development of these systems was based on the needs of much smaller grate-fired incinerators, where temperatures and gas species can change quite rapidly and can vary dramatically across the grate, Figure 4. Unsteady combustion conditions lead to wide variability in not only temperature, but also CO, NO_x, and O₂ concentrations that affect SNCR performance.

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Figure 4 Image of the highly non-uniform combustion on an incinerator grate

In simplified terms, the temperature profile can be mapped over an existing control scheme to activate only the injectors that are expected to provide the best performance. This can be managed in the short-term by responding to apparent conditions in the furnace. It has also been possible to measure variations in the furnace and develop algorithms to predict expected conditions in the near future. These algorithms include predictions of furnace gas concentrations and temperature changes that can be anticipated to improve chemical use and minimize balance of plant impacts. Potentially, integration with advanced combustion tuning system can provide even greater benefit, but this must be addressed individually on each application.

The optimized injection strategy is determined by reference to Fuel Tech's vast SNCR experience database, CFD and CKM models, and field evaluation. Each of these three components is critical to a successful commercial project. The approach to designing a highly flexible system is to recognize that the furnace has many different operational modes. There are large changes that occur with load variation and fuel switching, but there are also many other



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more subtle changes due to fuel moisture, mill behavior, and combustion air imbalance. The control theory must take into account each of the expected scenarios, and then recognize the variations from the norm. The approach is similar for any size unit, but the application can vary dramatically for very large furnaces.

The application of Advanced SNCR to a large utility furnace incorporates many of the described features in the Advanced SNCR description with many of the unique capabilities developed by Fuel Tech to treat very large furnaces. These include both mechanically and air atomized injectors as well as water-cooled multiple nozzle lances were appropriate. The specific design solution is custom-fit to the subject furnace as well as the unique customer requirements for the project.

RESULTS AND DISCUSSION

The Advanced SNCR application on Unit 4 at Drax Power Station is a particular challenge as it is already equipped with opposed-wall fired low-NO_x burners, the capacity for Mill-OFA and an additional Boosted-OFA system. Unit 4 is one of six 645MWn Units at the station that fire various coal and biomass fuels. Drax Power has made much advancement in the control of plant emissions including SO_x, fly ash, NO_x and net-CO₂. In addition, Drax utilizes an automated combustion-tuning package (SimSciAPC) that can iteratively improve combustion efficiency and reduce emissions through static and dynamic manipulation of the combustion conditions.

Construction and commissioning of the urea-based selective non-catalytic reduction system was initiated in 2015. Computational fluid dynamic models (CFD) and detailed chemical kinetic studies were completed to determine the optimal location for urea injection. This modeling included the provision for automatic injector control as determined by the on-line measurements of the combustion conditions. Initially, the system has been tuned to automatically respond to the generated electrical output, the measured NO_x at the stack, and to the grid of lower-furnace temperatures provided by the acoustic pyrometer. In addition, a manual selection criterion is available for other more specific operator choices or furnace observations.

The controlled NO_x level is highly dependent on the NO_x baseline, which is itself highly dependent on the fuel selection and staged combustion characteristics. Depending on the selection of mills and the operating unit electric generation (%Load) this baseline can vary between 180mg/Nm₃ (about 90ppm), corrected to 6% O₂ and 400mg/Nm₃ (about 200ppm), corrected to 6% O₂. Although every effort is made to minimize the baseline NO_x in practice, certain conditions were created to test at higher baseline NO_x concentrations.

In a previous industrial application of the technology, it was found that the primary control signal was based on the steam flow, but was coupled closely to the predicted future load profile.

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This predicted load profile came from analysis of the furnace conditions and the rate of change of certain key variables.

In this case, the utility furnace was found to respond best when “Generated Load” [MWg] was used as the primary control, with the furnace temperatures controlling a feed-forward to the injectors and the controlled NO_x level providing a feedback to the performance metric. The resulting NO_x control was nearly independent of NO_x baseline, but did vary significantly with relaxed ammonia slip constraints. This data, gathered during demonstration testing, is shown in Figure 5 and includes the baseline NO_x, the controlled NO_x and the average ammonia slip.

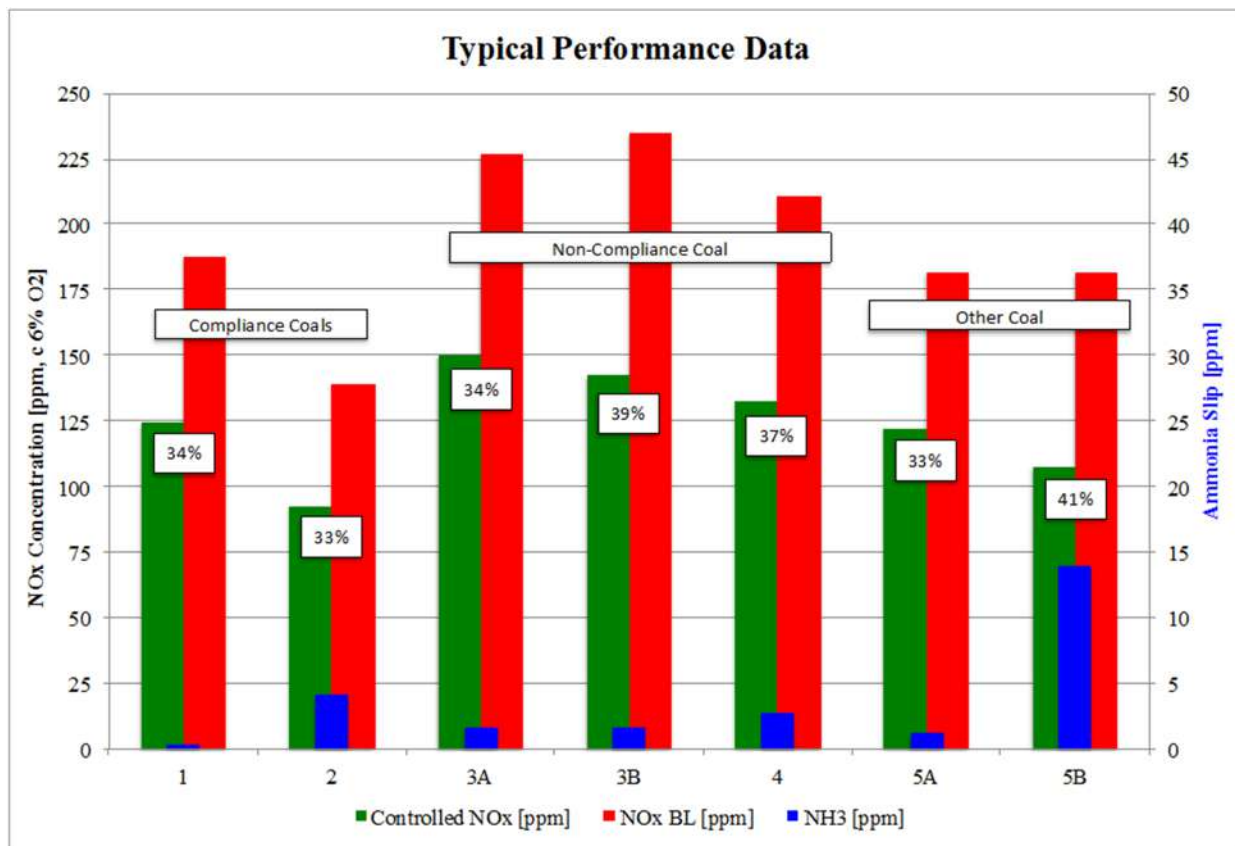


Figure 5 Performance of the ASNCR system for various coals.

Although it was somewhat easier to get a high reduction percentage at the higher baselines, there is not a strong correlation. The highest NO_x reduction occurred at a condition where the injection strategy led to the highest ammonia slip, Case 5B. This is typical of SNCR and can be controlled to provide additional NO_x reduction when additional ammonia slip is tolerable.



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Combustion Tuning Automation

Drax has subsequently utilized a process optimization package by Schneider Electric called SimSci-APC. This software enables evaluation over multiple variables and helps to determine dependency. By manually or dynamically altering various combustion parameters, such as damper positions, and evaluating the results, it eventually develops a set of conditions for optimal combustion performance.

The optimal condition must be defined and currently minimizing excess air and controlling CO are important metrics. These two variables act as surrogates for furnace efficiency and combustion completion or carbon-in-ash.

As a result of lowering the furnace excess air while simultaneously controlling the CO, the baseline NO_x is decreased and the controlled NO_x can be further reduced. In one test, the APC optimizer was initiated while the A-SNCR was in service. In this case, the controlled NO_x decreased by 20% and the SNCR chemical flow rate automatically decreased by a similar 20%.

Through a mix of primary measures, fuel selection, combustion tuning and Advanced Selective Non-Catalytic Reduction, significant control of NO_x emissions has been accomplished and Drax will use this suite of technologies to meet current and expected NO_x regulations.

SUMMARY

Fuel Tech SNCR systems have proven to be very effective on large furnace applications, with more than 32GW of direct experience since 2000 on units larger than 400MW. Primary methods of NO_x control have been implemented on many units over the past 20 years, including Low-NO_x Burners and Over-Fired Air systems. These modern systems have low NO_x baselines and yet require additional control for emissions compliance.

Fuel Tech has now installed and initiated the Advanced SNCR system on five utility furnaces (>600MW) for Drax Power Station in the United Kingdom. In each case, the large furnace was modeled using proprietary CFD and CKM techniques to characterize the possible transient conditions. The units were equipped with on-line furnace mapping capability that then guided the injection strategy automatically, as determined by the process model analysis.

Through a mix of primary measures, fuel selection, combustion tuning and Advanced Selective Non-Catalytic Reduction, significant control of NO_x emissions has been accomplished and Drax Power will use this suite of technologies to meet current and expected NO_x regulations.