An Assessment of Ultralow-NOx Combustion Technology for the Steel Industry

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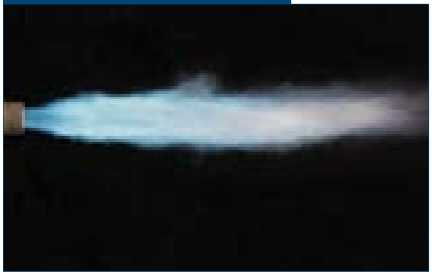
Environmental regulations are constantly changing based on the varying global landscape. Considerations on combustion systems' pollution impact will need to be made to stay in compliance with governmental regulations. There have been many low-NOx technologies implemented on a variety of steel processes. This paper will give a brief history and evolution of low-NOx approaches and present the current best offering for ultralow-NOx burners, as well as a look forward to emerging technologies.

Industrial combustion at its core is the mixing of air and fuel to produce heat for a specific process. However, design considerations must be made to maximize efficiency and product quality while minimizing emissions. For many years, emissions and fuel efficiency were not of concern to many industrial applications, so the technology focused on the type of burner (low/high velocity, flat flame, indirect fired, etc.) and the stability range. For steel, a wide variety of applications exist that require different types of burners. Most applications, such as ladle heaters or box-style heat treat and forge furnaces, would trend toward high-velocity burners with wide ranges of stability. For steel reheat furnaces, high-velocity burners (shown in Fig. 1) or flat-flame burners were generally chosen. The stability range was not as important due to the continuous nature of the furnaces. Finally, for strip furnaces, indirect radiant tube-fired burners were always chosen due to atmospheric considerations. Indirect-fired burners are not covered in this review.

Figure 1

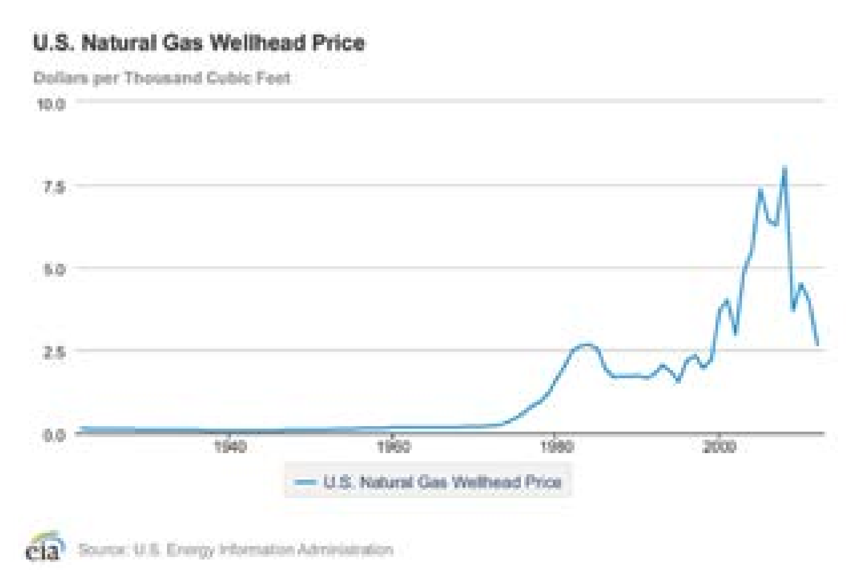


Typical high-velocity nozzle mix burner flame.

Drive for Fuel Efficiency — Combustion fuel efficiency has always existed in the steel market. However, as fuel prices have increased through the years (Fig. 2), fuel efficiency has become an emphasis in large energy-consuming processes. As seen in the figure, fuel prices rose sharply after the 1970s, causing many steel manufacturers to investigate cost savings. Large recuperators became the standard on steel reheat furnaces, while recuperative radiant tube burners started their evolution. Smaller processes, such as forging furnaces, utilized recuperative and regenerative technology to increase efficiency and lower the overall cost of their steel products.

Lowering Emissions Standards — Prior to 1970, emissions were not a concern, but with the formation of the U.S. Environmental Protection Agency (EPA), all pollutants started to be monitored. Reduction of pollutants increased in importance with the Clean Air Act of 1990, which had specific amendments designed to

Figure 2



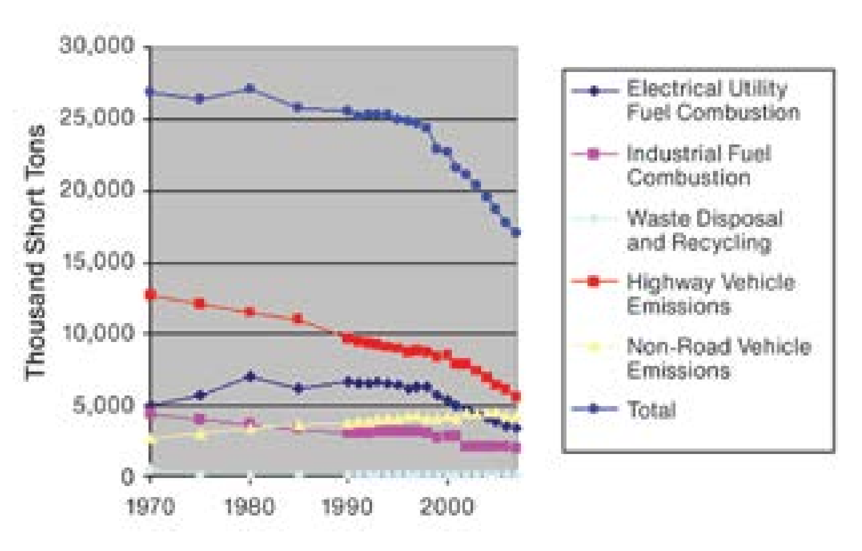
U.S. natural gas wellhead prices over the last 100 years.[1]

curb four major threats to the environment and health of people. These four threats were acid rain, urban air pollution, toxic air emissions and stratospheric ozone depletion. Nitric oxides (NOx) contribute to several of these and therefore, regulations were enacted to start decreasing NOx from all sources of combustion. Acceptable NOx levels differ across the world, with some of the strictest existing in the Southwestern United States. As shown in Fig. 3, NOx emissions have been reduced in the U.S. by about 50% since the formation of the EPA, really starting their downward decline after the Clean Air Act of 1990. NOx regulations, along with other pollutants, will continue to be reduced in the future as the importance of clean environment and global warming initiatives come into play.

NOx in the Steel Industry — As fuel prices have increased and NOx regulations have come into force, the need for fuel efficiency and low-NOx combustion equipment has grown. The conventional way to achieve fuel savings in industrial combustion is to pre-heat the combustion air through either a recuperator or a regenerator. However, this negatively affects the ability to lower NOx emissions as NOx is a function of temperature, residence time, and the amount of nitrogen and oxygen. To lower NOx, combustion equipment suppliers have focused on ways to reduce the local temperature in the furnace where NOx could form while maintaining low localized oxygen concentrations. The keys to NOx minimization are:

- Limiting of peak temperatures (keep below 2,500°F).
- Cool the products of combustion stream quickly.
- Limit oxygen availability.
- Avoid fuel-rich regions.

Figure 3

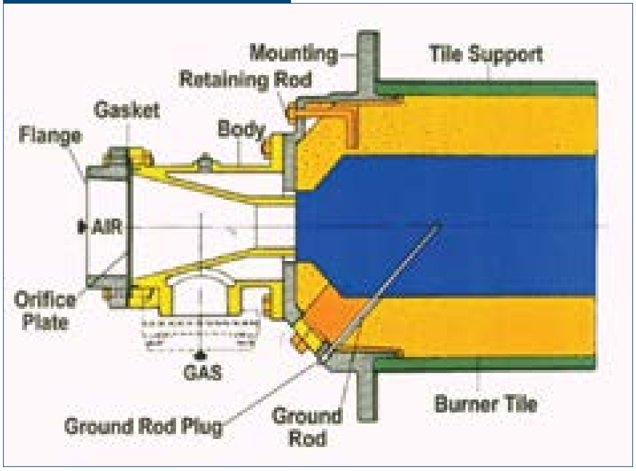


U.S. NOx emissions since 1970.[2]

There are many combustion equipment suppliers that have ultralow-NOx technology but all of it is based on the keys presented herein. The major methods of achieving ultralow-NOx emissions are air/fuel staging, rich core technology, lean pre-mix, and diffuse mode combustion (DMC). All will be reviewed in the following sections.

Prior to discussing the NOx reduction methods, it is important to briefly discuss traditional industrial burners, most of which could be categorized as nozzle mix burners. Nozzle mix burners mix air and fuel at the point of ignition inside a flame retention tile. The flame is held inside the tile using some sort of stabilization method. The tile can vary

Figure 4



Typical nozzle mix burner.

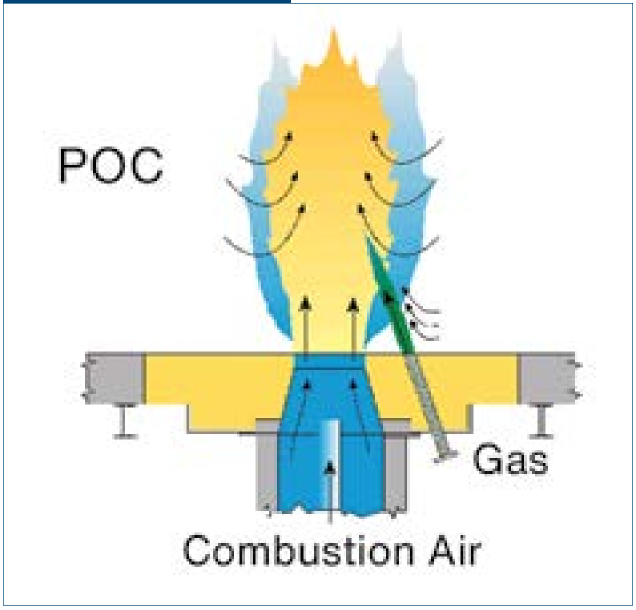
in shape to give the flame jet the velocity or shape desired for the process. A typical schematic of a nozzle mix burner is shown in Fig. 4. An example of a nozzle mix burner that is prevalent throughout the steel industry is the North American Tempest® burner.

Air/Fuel Staging — As seen in the nozzle mix burner, the air and fuel are introduced in the back of the burner. However, when staging, either the air or fuel will be introduced downstream of its typical injection point. Many times, air or fuel are introduced directly into the furnace itself. As previously discussed, NOx is a function of peak temperatures and oxygen availability. By staging air or fuel into the furnace itself, the oxidant stream is diluted by other products of combustion (POC) prior to combustion, thus lowering the localized oxygen concentration from 20.9% (traditional air) to 5–7%. This in turn reduces the peak flame temperature and lowers NOx.

A schematic of fuel staging is shown in Fig. 5. This shows the North American LNI™ concept. As shown, fuel is injected downstream of the typical burner, while air still flows through the burner. The POC dilutes the air and fuel streams, and combustion takes place in the furnace itself. This is what is referred to as flameless combustion in the industry.

Low NOx Injection (LNI) is a fuel staging technology employed on several North American products to achieve ultralow-NOx emissions. It can be applied to regenerative, recuperative and cold air burners. This technology is applicable to steel reheat furnaces and batch furnaces. The fuel staging is done through an

Figure 5

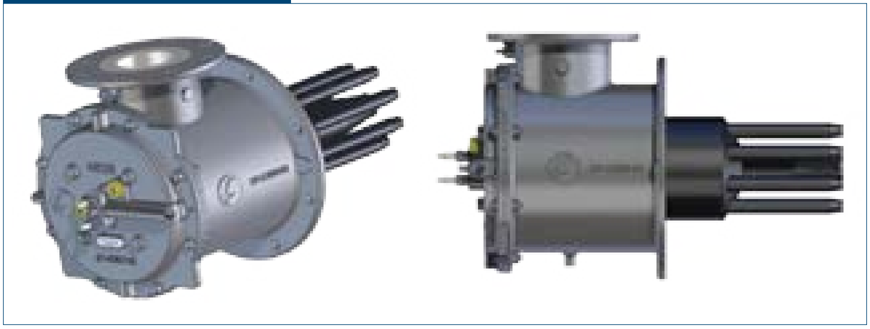


Low NOx Injection (LNI™).

alloy nozzle placed outboard of the traditional burner tile. This technology only works when combustion can sustain itself in the furnace, which is qualified by the autoignition temperature (1,400°F). Fig. 5 shows the typical installation. This is applied to Fives' high-velocity product line (North American Tempest, North American HiRam®, North American MagnaFlame™) and the TwinBed™ II Regenerative burner line. NOx reductions with LNI are significant. In the regenerative burner product line, NOx reductions can be as high as 90%. In cold air and recuperative applications, NOx reduction can range from 50% to 70%.

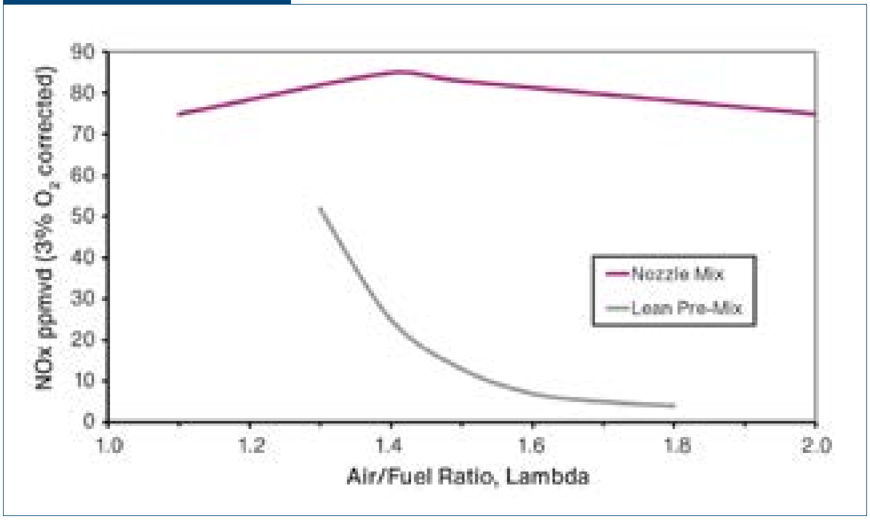
Rich Core — The North American Centinel™ burner employs rich core technology to reduce NOx while being able to run air pre-heat temperatures up to 1,200°F (650°C). As seen in Fig. 6, the burner has a core element that runs fuel rich while flowing the

Figure 6



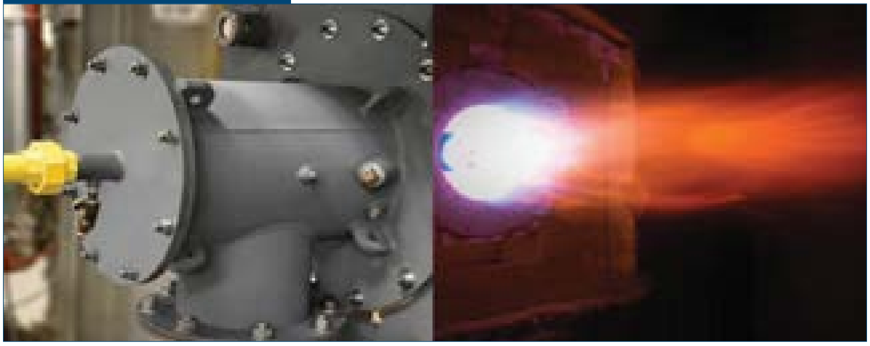
The North American Centinel™ burner.

Figure 7



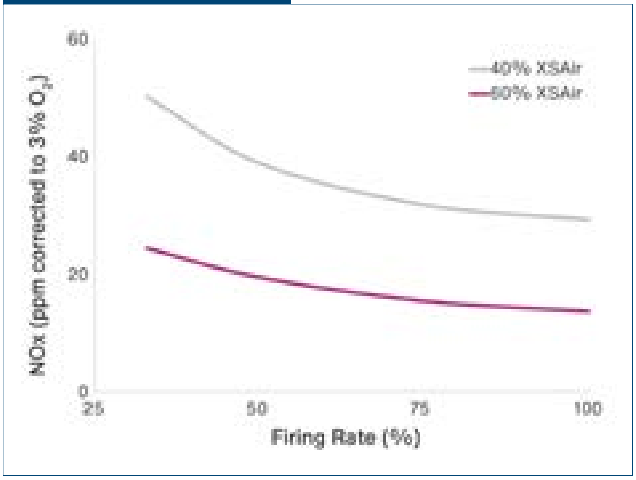
NOx comparison between nozzle mix and lean pre-mix technology as a function of air/fuel ratio.

Figure 8



The North American EcoFornax™ SLEx.

Figure 9



NOx as a function of firing rate for the North American EcoFornax SLEx.

balance of air in the outside nozzles. This burner ranges in input from 0.4 MMBtu/h (120 kW) to 3 MMBtu/h (900 kW).

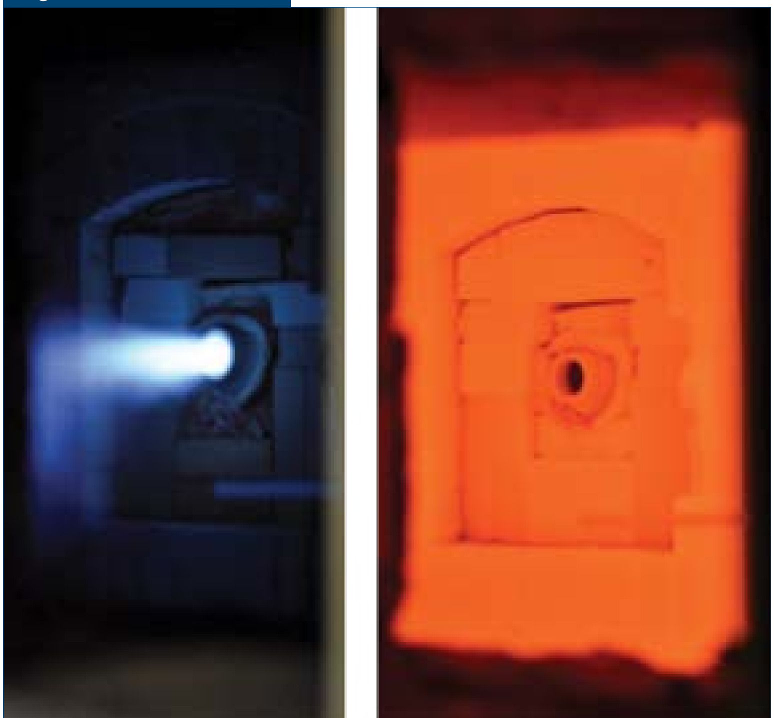
The burner was designed for pre-heated air usage with a lightweight tile. The primary application would be mostly for process lines, but other applications might be well suited for use. The NOx performance at 1,200°F air pre-heat temperature ranges between 60 ppm and 90 ppm at 2,200°F furnace temperature. This is compared to traditional burner technologies producing between 300 ppm and 400 ppm at this same operating condition.

Lean Pre-Mix — Lean pre-mix technology mixes the air and gas prior to ignition. It is different from traditional pre-mix as the mixing is done in the burner itself. By doing this, the mixing process is decoupled from the combustion process and more homogeneous combustion is achieved. The flame length is determined by ignition delay and chemical reaction time. The pre-mix is intentionally run lean (higher excess air) to reduce the peak flame temperature and thus reduce the NOx. Fig. 7 shows the effect of air/fuel ratio on NOx levels in the lean pre-mix technology compared to the typical industrial nozzle mix burner. If oxygen concentration is of concern, an outboard injector similar to an LNI nozzle can be installed to balance the POC stream closer to stoichiometric. As it can be seen, the NOx levels from this technology are of the lowest that can be achieved in the marketplace, typically below 30 ppm.

The North American EcoFornax™ SLEx is useful in many different steel applications, such as ladle/tundish heaters, ovens, dryers and furnaces. The EcoFornax SLEx has a single air and fuel connection and employs a self-supporting tile that can be easily installed in ceramic fiber-insulated furnaces. The burner is shown in Fig. 8. Fig. 9 shows typical NOx emissions with varying excess air rates.

Diffuse Mode Combustion — DMC is a NOx reduction technique where the conventional burner is turned off above autoignition and allowed to extinguish then the fuel and air are reintroduced through the

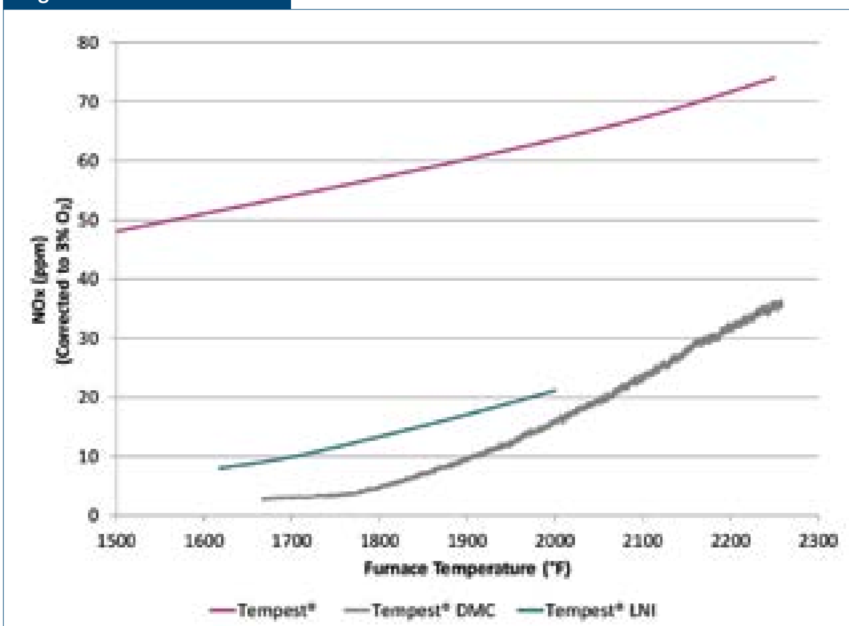
Figure 10



(a) (b)

Tempest DMC firing in conventional (a) and DMC (b) mode.

Figure 11



NOx comparison between standard Tempest, Tempest DMC and Tempest LNI.

same air and fuel paths without igniting it in the burner body. This allows the fuel and air mixture to enter the furnace and then ignite using the energy of the surrounding gases. This technology can only be used above autoignition temperatures. This is a patented technology by Fives North American Combustion and is currently utilized on the North American Tempest product line. Fig. 10 shows the Tempest DMC burner firing traditionally and in DMC mode. DMC mode is a flameless combustion technology, so no flame front is visible.

Fig. 11 compares NOx emissions as a function of furnace temperature for the North American Tempest burner when firing in various modes: traditional, LNI and DMC. Results for all tests were obtained with ambient temperature combustion air.

Conclusions

Several ultralow-NOx techniques have been presented along with products that utilize these approaches. Given the vast number of applications that exist in the steel marketplace, different approaches will need to be implemented to fit the process and maximize productivity and efficiency. Air/fuel staging is currently the most widely used NOx reduction technique as it is an easily retrofittable technology to conventional burners, especially if outboard fuel injectors are installed, such as the LNI technology. New advances such as rich core and diffuse mode combustion have introduced ultralow-NOx capabilities to new processes such as forge, heat treat or direct-fired strip furnaces. A summary graph comparing the different technologies is shown in Fig. 12.

Current NOx standards — both domestically and internationally — will continue to decrease in the next decade. Carbon reduction initiatives will drive to increase fuel efficiency or switch to hydrogen fuels. With the increase in fuel efficiency, the effect on NOx emissions will be detrimental. However, the current technology in the marketplace has the capability to achieve lower NOx than most current regulations in the global marketplace.

References

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2. Air Emissions From MSW Combustion Facilities | energy recovery from waste, retrieved 16 April 2021, from https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/airem.html. ✦

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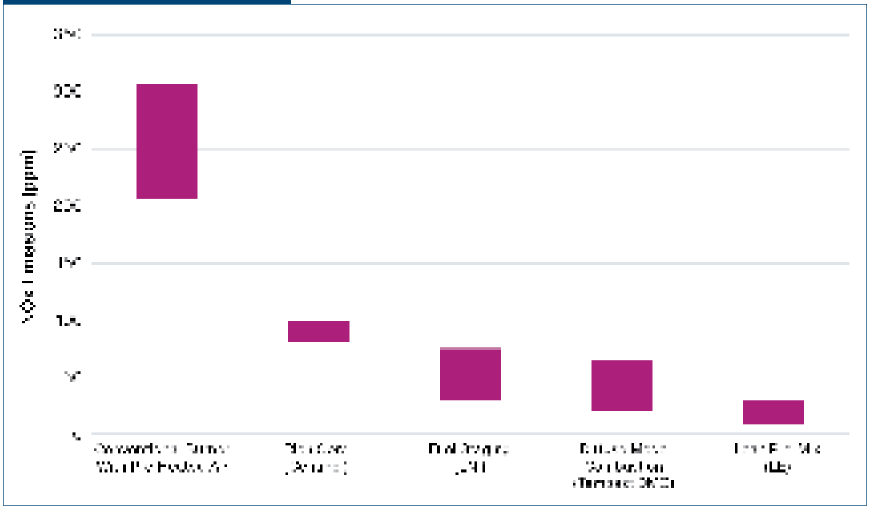
Figure 12



Ultralow-NOx technology comparison.