



TEXAS
TECHNOLOGY 2003
Showcase

March 17-19, 2003

Houston, Texas

Energy Efficiency in the
Chemical and Refining Industries

Calpine Corporation

Tour Guide Book
Baytown Energy Center



U.S. Department of Energy
Energy Efficiency
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Texas Industries of the Future

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Plant Overview

Calpine Corporation

Baytown Energy Center

Founded in 1984, the Calpine Corporation is the leading independent power company in the United States, with over 19,000 MW of capacity in operation and 10,000 MW of capacity under construction. Calpine generates and markets power through plants it develops, owns, and operates in 23 states in the United States, 3 provinces in Canada, and the United Kingdom. Calpine is the world's largest producer of renewable geothermal energy and owns approximately one trillion cubic feet of proven natural gas reserves in Canada and the United States.

With the exception of 900 MW of geothermal generation capacity in northern California, Calpine uses natural gas to generate power. This fuel source, combined with state-of-the-art combustion and emissions control technologies, enables Calpine to provide its customers with clean, efficient, and reliable energy.

Calpine's Baytown Energy Center (BEC) in Baytown, Texas, began operations in June 2002 and is one of 75 natural gas-fired power plants operated by the company. This combined-cycle cogeneration facility has a base capacity of up to 700 MW throughout the year plus an additional 130 MW of "peaking" power during the hot summer months. The BEC provides the neighboring Bayer Corporation chemical facility with all of its electricity and steam needs under a long-term contract. The remaining electric capacity joins Calpine's ERCOT (Electric Reliability Council of Texas) portfolio and is sold into the ERCOT wholesale and retail markets.

The BEC's combined-cycle operation generates electricity using three natural gas-fired combustion turbines, and then recovers thermal energy from the hot combustion exhaust to create steam. The steam is used to generate additional electricity in a steam turbine. This combined-cycle operation enables the BEC to produce electricity with 30% less fuel than the average fossil fuel-fired plant in Texas.

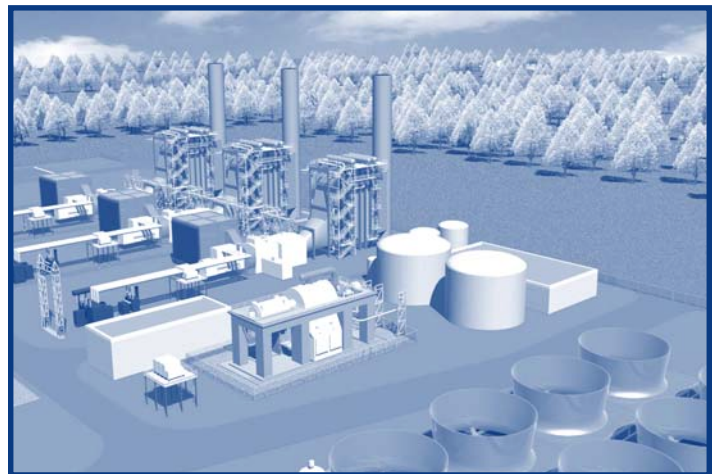
To make more complete use of the excess steam available, the BEC routes a portion to the Bayer plant to satisfy its steam requirements. BEC thus generates and uses both power and thermal energy (steam) from a single fuel source

for industrial purposes. This approach, known as cogeneration, improves the BEC's efficiency by 10%.

Together, the combined-cycle operation and the cogeneration of electricity and steam produce a net heat rate of approximately 6,200 Btu per kWh, which is about 40% lower than the average fossil fuel-fired plant in Texas.

To reduce emissions, the BEC uses a combination of low-NO_x combustion systems and selective catalytic reduction (SCR) technology. These technologies enable the BEC to produce electricity with 90% fewer NO_x emissions and 45% fewer CO₂ emissions than the average fossil fuel-fired generation facility in Texas. Extending this comparison to annual performance, the Baytown facility represents potential emissions reductions of 7,000 tons of NO_x, 13,000 tons of SO₂, and 2.9 million tons of CO₂. Moreover, the BEC's arrangement to supply steam to Bayer has allowed Bayer to cease operation of its boilers, which had much higher emission rates.

Beyond reducing emissions, the BEC also conserves water by recycling storm water and boiler blowdown to help maintain the cooling tower water supply. Additionally, the BEC receives back over half of the condensate associated with the steam that it sends to Bayer.



Typical Calpine Power Generation Plant

Combined-Cycle Cogeneration for Increased Energy Efficiency

America's demand for electricity is met by a diverse collection of power generating facilities that use an array of fuels, technologies, and systems. The Baytown Energy Center's (BEC) natural-gas fired, combined-cycle cogeneration operation is among the cleanest and most efficient systems in use.

The BEC, owned by the Calpine Corporation, has a generating capacity of 700 MW with an additional 130 MW of peaking capacity. Combined-cycle cogeneration operations at the BEC began in June 2002. The BEC provides electrical power not only to the wholesale grid but also to the neighboring Bayer Corporation chemical facility.

The BEC's superior efficiency relative to traditional fossil fuel-fired plants is the result of two systems — combined-cycle and cogeneration. "Combined-cycle" refers to the utilization of thermal energy in the combustion turbine exhaust to produce steam for additional power generation. In "simple-cycle" plants, this exhaust is expelled into the atmosphere, and the thermal energy contained in the exhaust is not captured to produce power.

A cogeneration facility is a plant that produces both electrical energy and a form of useful thermal energy (such as steam) for industrial purposes. At the BEC, a portion of the steam that is generated is diverted to the Bayer facility for process operations. A typical combined-cycle system will use only about a third of the steam's energy for power production, with the rest being channeled through a cooling tower and into the atmosphere. The use of cogeneration (e.g., Bayer's use of the steam) results in much greater utilization of the steam's thermal energy, making the overall process more efficient.

Benefits

- 40% reduction in fuel per kWh compared to the average fossil fuel-fired plant in Texas.
- Potential reductions of up to 7,000 tons of NO_x, 13,000 tons of SO₂, and 2.9 million tons of CO₂ in annual emissions compared to the average fossil fuel-fired plant in Texas.

Technology Description

The principal components of the combined-cycle cogeneration operation used by the BEC are shown in Figure 1. The primary fuel input to the plant is natural gas, which is fired with compressed inlet air in the gas turbine. The high-temperature, high-pressure products of this combustion expand in a turbine, which drives a generator and creates electricity. Hot exhaust gas from the combustion turbine is routed to a heat recovery steam generator (HRSG), where the thermal energy of the exhaust gas is used to generate high-pressure steam. The exhaust gas from the combustion turbine is cooled from roughly 1,100°F to 220°F by heat transfer in the HRSG. (In simple-cycle operations, this thermal energy in the exhaust gas is wasted.) The cooled combustion exhaust gas is then treated by selective catalytic reduction (SCR) inside the HRSG to reduce NO_x emissions prior to release from the plant.

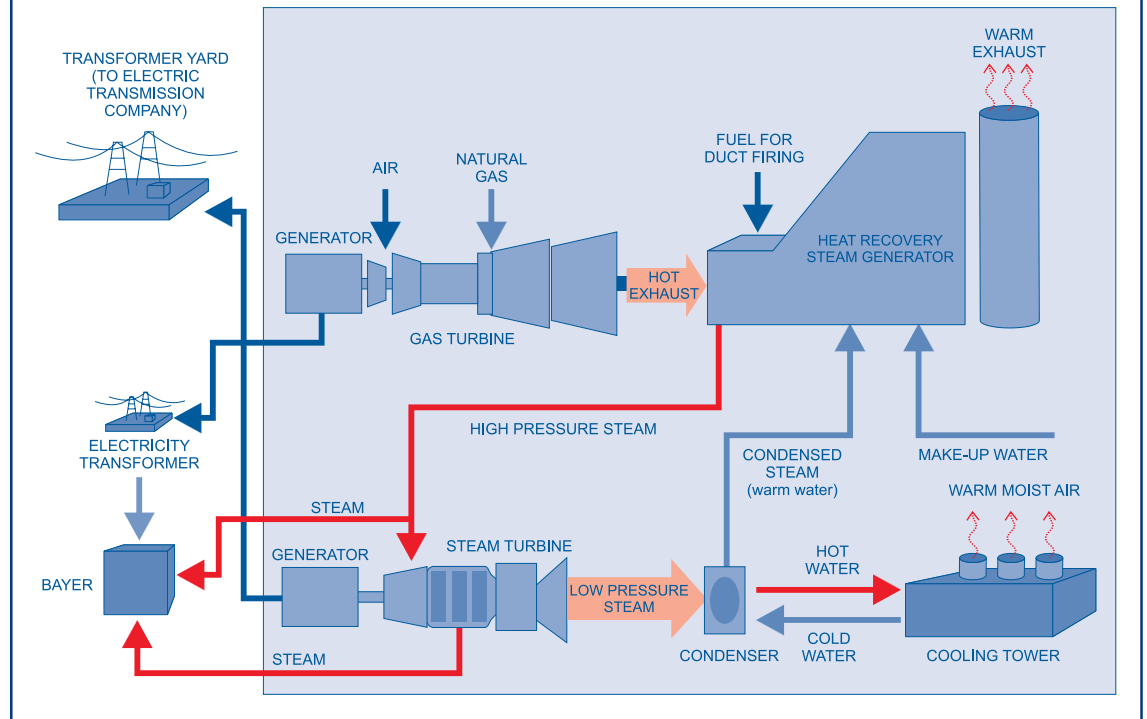


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Figure 1: Combined-Cycle Cogeneration Schematic



Within the plant, the high-pressure steam output from the HRSG drives a steam turbine, which in turn powers a generator to create additional electrical energy. Low-pressure steam output from the steam turbine is routed through a condenser and then looped back through the HRSG.

The figure also depicts the electricity and steam flows that are delivered to the Bayer facility for its operations. A separate transformer station is used to step up the voltage of electricity transmitted to Bayer.

The BEC's additional peaking capacity of 130 MW relies upon duct firing in the HRSG to generate additional steam, which is expanded through the steam turbine generator for conversion into electricity. The BEC requires about 6,200 Btu of fuel to generate 1 kWh of electricity, as opposed to 10,400 Btu per kWh required by the average fossil fuel-fired Texas power plant. This 40% reduction is a result of the extra electricity created by steam generated in the HRSG unit, combined with the added efficiency benefits of cogeneration.

Cogeneration and Its Role in Regional NO_x Reduction

The Houston-Galveston area (HGA) is classified as a severe nonattainment area for ozone under the 1990 Amendments to the Clean Air Act. By law, this eight-county area must reduce emissions to meet specified ozone standards in the coming years.

Ozone is an air pollutant that is not directly released into the air but formed by chemical reactions when particular precursors are present. Nitrogen oxides, or "NO_x," are one of the primary precursors for ozone formation and can lead to ground-level ozone, haze, and acid rain. NO_x emissions are typically a by-product of the high-temperature combustion processes characteristic of power generation, automobiles and trucks, furnaces, and industrial boilers.

One of the most effective ways to reduce ozone is to reduce NO_x emissions from major sources. Accordingly, the Texas Commission on Environmental Quality (TCEQ) has established a regional NO_x reduction program for the HGA. This program imposes strict NO_x requirements on emission sources in the HGA, including both power generation and industrial plants.

Cogeneration and Regional NO_x Reduction

A cogeneration facility is a plant that produces both electrical energy and a form of useful thermal energy for industrial purposes. Power generation plants like Calpine's Baytown Energy Center (BEC) use cogeneration to harness the energy from natural gas to produce both electrical and thermal (steam) energy.

The prior write-up, *Combined-Cycle Cogeneration for Increased Energy Efficiency*, explains the efficiency advantages of combined-cycle cogeneration. In addition to energy efficiency, these systems also offer significant environmental benefits, especially in an atmosphere of strict NO_x regulation.

Benefits

- Highly efficient production of steam and electricity from Calpine's six cogeneration operations.
- Displacement and reduction of industrial air emissions (such as NO_x) throughout the Houston-Galveston area.

As the map of the 8-county nonattainment area shows (Figure 1), the region's heavy industrial activity results in high NO_x emissions. Four of the eight counties produced annual NO_x emissions of more than 30,000 tons in 1996. The average NO_x emissions level for all other Texas counties was 6,600 tons in 1996 (Source: U.S. Environmental Protection Agency). Further, all of these industrial plants in the HGA require electrical power, and most require steam as well. In the face of stringent NO_x reduction requirements, many of these plants are severely challenged with balancing emission controls, economics, and regulatory compliance—all while striving to maintain productivity and performance.

Cogeneration power plants like the BEC and Calpine's five other HGA facilities (Figure 1) fit well into this environment because of their efficiency, reduced environmental impact, and ability to supply electrical power and steam directly to industrial neighbors. Calpine's cogeneration operations produce both steam and electricity within the same process, which is more efficient than producing the two energy outputs separately. The BEC, for example, is approximately 40% more efficient than the average fossil fuel-fired power plant in Texas.



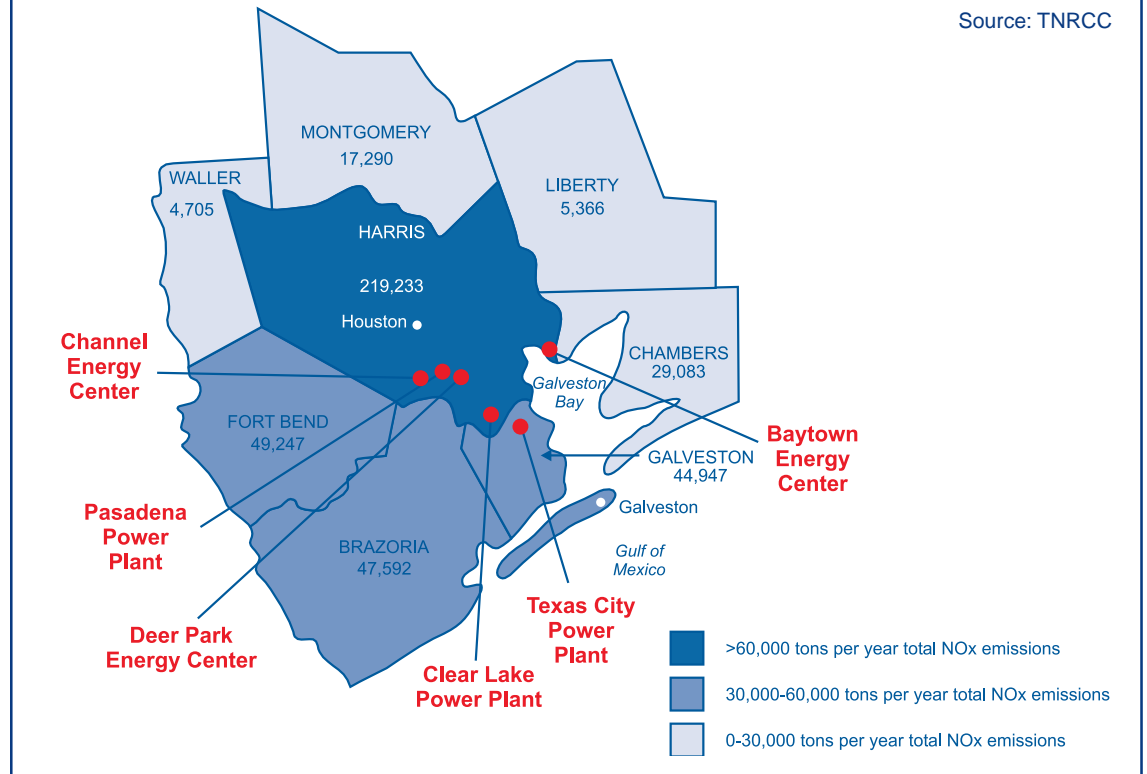
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Figure 1: 1996 NO_x Emissions for the Houston-Galveston Area

Source: TNRCC



Environmentally, combined-cycle cogeneration plants like the BEC offer two key advantages in meeting regional NO_x reduction requirements: increased efficiency and displaced emissions. The increased efficiency realized by combined-cycle cogeneration translates into a lower fuel input per unit of energy output, which reduces NO_x emissions.

Cogeneration operations like those of the BEC supply steam directly to neighboring industrial facilities. The useful application of steam at a nearby facility like Bayer displaces the need for less efficient and more polluting steam generation at individual plants. This arrangement also helps to reduce regional NO_x emissions. The steam generation at the BEC employs emission control technologies (selective catalytic reduction and low-NO_x combustion) to significantly reduce NO_x emissions.

The relationship between the BEC and Bayer is just one example of six such Calpine operations in the HGA. This approach to steam and power production benefits both Calpine and its industrial neighbors, while helping to meet regional NO_x reduction goals. In total, these combined-cycle cogeneration plants, when compared to the average Texas fossil fuel-fired generation facility, have the potential to reduce NO_x emissions by approximately 30,600 tons per year, SO_x emissions by 56,800 tons per year, and CO₂ emissions by 12.7 million tons per year. Further, these values are based solely on the cleaner electric power that Calpine supplies to its industrial neighbors and do not include the emissions reductions achieved by shutting down old boilers at the steam recipient sites.

Achieving NO_x Reductions with Selective Catalytic Reduction Technology

Introduction to NO_x

Combustion of fuel to release thermal energy is an integral process in many industries, especially for heat-intensive industries like power generation, petroleum refining, and chemical production. The emissions that result from combustion, however, can be detrimental to people and the environment. Pollutant emissions like nitrogen oxides, or "NO_x", can contribute to the formation of ground-level ozone, haze, and acid rain. Accordingly, industry must comply with government-mandated emission requirements.

NO_x formed during the combustion process can be categorized as *Fuel NO_x*, *Prompt NO_x*, or *Thermal NO_x*. Fuel NO_x is formed when nitrogen contained in a combustion fuel (e.g., coke oven gas) is converted to NO_x molecules during the combustion process. Natural gas does not contain a significant amount of nitrogen, and thus does not produce fuel NO_x.

Prompt NO_x is formed in a fast reaction that takes place between hydrocarbon fragments and atmospheric nitrogen found in combustion air or other air sources. This reaction takes place within fuel-rich regions of the combustion zone. Control of prompt NO_x formation is most critical when the goal is to attain the lowest possible levels of NO_x emissions.

Thermal NO_x formation occurs with the high-temperature oxidation of atmospheric nitrogen found in combustion air or other air sources. Thermal NO_x formation is the most prevalent mechanism for NO_x formation, and the conversion rate into NO_x is strongly dependent on the combustion temperature.

Overall, the primary controlling factors for NO_x formation are flame temperature, residence time, extent of fuel/air mixing, nitrogen content of the fuel, and the quantity of excess air used for combustion.

Benefits

- 90% reduction in NO_x emissions.
- Contribution toward compliance with NO_x emission requirements of the Texas Commission on Environmental Quality.

NO_x Reduction

The Houston-Galveston area (HGA) is a severe non-attainment area for ozone under the 1990 Amendments to the Clean Air Act. Since NO_x is a precursor for the formation of ozone, the HGA has established a rigorous NO_x reduction program. Point sources of NO_x, such as industrial facilities and power generation plants, must rely on emission control technologies to comply with new NO_x requirements.

The technologies used to reduce NO_x emissions fall into two categories: combustion-modification and post-combustion. Combustion-modification technologies control NO_x formation factors such as flame temperature and fuel/air mixing to limit the formation of prompt and thermal NO_x. Post-combustion technologies remove all types of NO_x from combustion exhaust gases. Both economics and NO_x reduction capabilities play a large role in determining which technologies a facility will adopt. Often a mix of combustion-modification *and* post-combustion technologies is the most effective solution in terms of NO_x reduction and capital and O&M costs.



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Technology Description

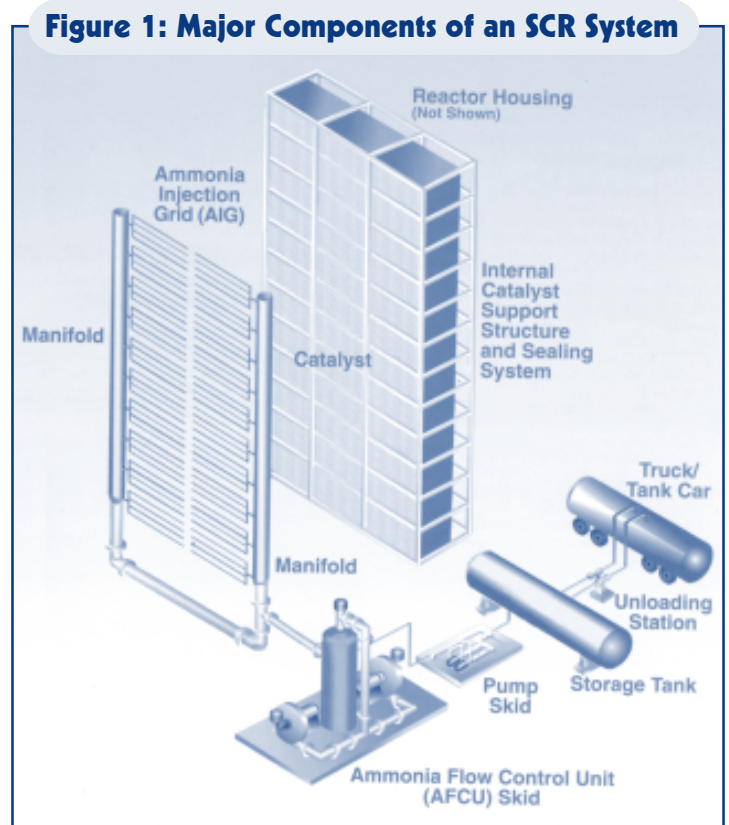
A widely applicable post-combustion technology for NO_x reduction is selective catalytic reduction (SCR). SCR injects ammonia into the exhaust stream from the combustion source (e.g., boiler, combustion turbine). The mixture of ammonia and combustion gas then passes through a catalyst bed in a reactor, where the catalyst facilitates a reaction between the ammonia and NO_x . The reaction products are nitrogen (N_2) and water vapor. This reaction takes place in a temperature range of roughly 280°C to 500°C .

At the Baytown Energy Center, the SCR system is located inside the heat recovery steam generators (HRSGs), where it effectively reduces NO_x in the exhaust gases from the natural gas-fired combustion turbines. The ammonia storage, ammonia handling equipment, and injector grid for the SCR system were supplied by Peerless Manufacturing under subcontracts with Nooter Eriksen, Inc. The catalyst component of the system was supplied by Cormetech, Incorporated.

The primary components of an SCR system are shown in Figure 1. The ammonia storage, forwarding equipment (flow control, pumps, etc.), manifold, and injection grid all facilitate the introduction of ammonia into the combustion exhaust gas stream. The actual reaction of the ammonia and NO_x molecules takes place within the catalyst bed. Packaged SCR systems are available for small applications, while large facilities such as power plants typically require custom-engineered systems. SCR technology can be installed in heat recovery steam generators like those at the Baytown Energy Center, as well as on boilers, engines, and refinery heaters.

One potential drawback of SCR technology is the emission of unreacted ammonia from the stack, or “ammonia slip.” This is an important performance issue for SCR systems, and some jurisdictions have established limits for ammonia slip of 5 parts per million or lower. Factors that affect ammonia slip include the quantity of ammonia in the exhaust gas and the reaction activity in the catalyst.

Use of SCR technology at the Baytown Energy Center reduces NO_x emissions by over 90%, achieving emission levels as low as 2 parts per million.



Single-Digit NO_x Emissions with Low-NO_x Burners

The prior write-up, *Achieving NO_x Reductions with Selective Catalytic Reduction Technology*, explains the connection between NO_x emissions, ozone formation, and NO_x regulations in the Houston-Galveston area. The use of selective catalytic reduction (SCR) to reduce NO_x emissions from Calpine's Baytown Energy Center (BEC) is also explained.

While SCR is an effective *post-combustion* technology to reduce NO_x, low-NO_x burners are a highly effective *combustion-modification* technology for NO_x reduction.

Technology Description

Low-NO_x burners (LNBs) are a proven and cost-effective combustion-modification technology that helps facilities like the BEC reduce NO_x emissions. Since LNBs are a combustion-modification technology, they *prevent the formation* of NO_x as opposed to *removing* NO_x once it is formed. These burners prevent NO_x formation by controlling key factors such as flame temperature and fuel/air mixing.

The BEC employs TODD Rapid Mix Burners (RMB™) in its two auxiliary boiler units. These low-NO_x burners utilize fuel/air mixing technology and flue gas recirculation (FGR) to severely limit the formation of NO_x during combustion.

As Figure 1 shows, a mixture of combustion air and flue gas (the exhaust of combustion that has already taken place) passes through a set of axial swirl vanes. These swirl vanes are machined for gas injection, allowing thorough mixing of the fuel/air mixture within the swirl vanes. This design creates an ideal fuel/air mixture and eliminates the development of fuel-rich regions. Prompt NO_x formation is nearly eliminated as a result.

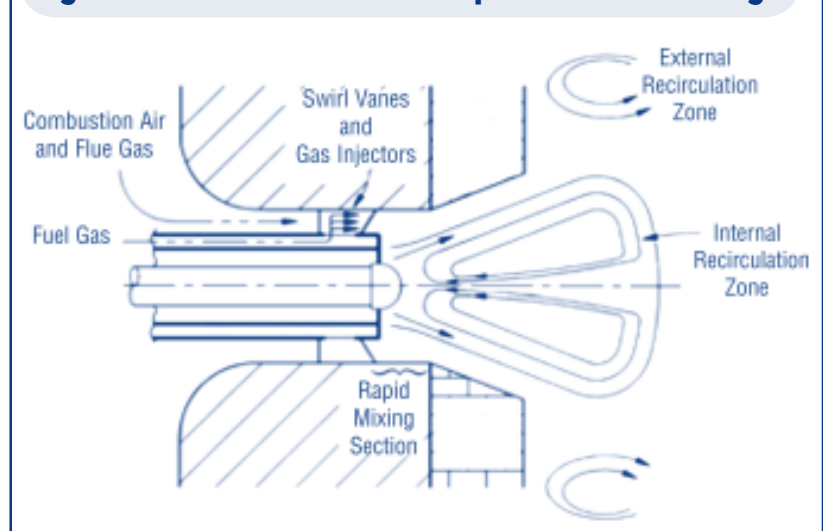
Benefits

- A proven, cost-effective method of preventing NO_x formation.
- Guaranteed single-digit NO_x emissions from the BEC's auxiliary boilers.

The recirculation of flue gas with the incoming combustion air takes place upstream of the burner and helps to reduce flame temperature. This feature is critical in controlling thermal NO_x formation within the burner.

With the factors that affect prompt NO_x and thermal NO_x formation controlled by the burner design and the use of natural gas as the fuel (no fuel NO_x), emissions from the BEC's auxiliary boilers are extremely low. In fact, the RMB™ burners have a guaranteed NO_x level of no more than 9 parts per million, which is low enough that the auxiliary boiler exhaust at the BEC does not require additional treatment with SCR technology.

Figure 1: Schematic of TODD Rapid Mix Burner Design



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The auxiliary boilers at the BEC, which are each rated at 375,000 pounds per hour of steam, are used for two purposes. First, they are a backup to the natural gas-fired combustion turbines. If the turbines are taken off-line, the auxiliary boilers are available to generate steam to satisfy the contractual agreements with Bayer.

Second, when the combustion turbines are running at a reduced rate during periods of low power demand, the rate of power production may be inadequate to generate sufficient steam to satisfy Bayer's requirements. In these cases it is more economical to use the auxiliary boilers to generate steam and keep the combustion turbines at a low generating rate.

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