Fossil Fuel Emission Levels
Pounds per Billion Btu of Energy Input

Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Reduction of carbon dioxide emissions is always a chief concern from

gas combustion, due to the fact that the characteristically low nitrogen content of natural gas, NOx formation from fuel NOx is insigniþcant.

So, why worry about reducing NOx emissions when most are concerned with eliminating greenhouse gases, in the form of CO_2 emissions? There are several answers to that question. The þrst is an issue we are all too familiar with, being located in Southern California. Smog. Speciþcally, photochemical smog, a major component of which is NO_2. The majority of NOx produced during combustion (approximately 95 percent) is in the form of NO. Once emitted into the atmosphere, however, NO is rapidly and continuously oxidized to form NO_2. Where high concentrations of this compound and certain other volatile organic compounds (VOCs) accumulate and react in the presence of sunlight, photochemical smog is formed. NO_2 molecules themselves, in high concentrations, have been found to cause damage to sensitive lung tissue in senior citizens, children, and those with preexisting heart and lung conditions.

Another major component of photochemical smog is tropospheric ozone, which is also produced as a byproduct of NOx emissions. Tropospheric ozone is ozone (O_3) which is formed and concentrated near ground level, when sunlight causes an NO_2 molecule to react with a VOC molecule to produce NO and ozone. The NO molecule then reacts with free radicals in the atmosphere to produce a new NO_2 molecule. In this way, each molecule of NO can produce ozone multiple times. This process repeats until the VOC molecules are reduced to short chains of carbon compounds that cease to be photo reactive. A VOC molecule can usually support this process about 5 times. Ozone is exceedingly dangerous, because it reacts strongly to destroy or alter many biological molecules, and can reduce forest growth and crop yields in high concentrations. In humans, ozone can reduce lung capacity and worsen pre-existing heart and lung conditions. The negative effects of tropospheric, ground level ozone contrast sharply with the protection from harmful UV-B radiation provided by the layer of stratospheric, or upper atmospheric, ozone, known as the ozone layer.

A third effect caused by excessive NOx emissions is acid rain. NO_2 can dissolve in atmospheric moisture to form nitric acid, a component of acid rain. Although nitric acid is not particularly harmful to humans, except in concentrations much higher than could be achieved by this process, it can be harmful to plant life and structures. By the same process that creates nitric acid in the atmosphere, NO_2 has been found to contribute the eutrophication of coastal and stagnant waters. Eutrophication occurs when a body of water suffers an increase in nutrients that leads to a reduction in the amount of oxygen in the water. This produces an environment that is

of high excess air (fuel lean) mixtures results in ÿame instability at high capacities. By pre-mixing the fuel and air in a primary chamber, distributing the mixture through a mesh of metal or ceramic þber, and maintaining combustion uniformly across the surface of this mesh, combustion stability is preserved, and NOx formation is greatly reduced. This technique eliminates the need for external piping required for the FGR system, and achieves a lower ÿame temperature by operating leaner, while at the same time creating a homogenous mixture of fuel and air to prevent the existence of fuel rich combustion zones. In certain applications, this system is capable of reducing the formation of NOx by as much as 90 percent.

The þrst technique is to use a ÿue gas recirculation (FGR) system. In a FGR system, a portion of the exhaust gas (ÿue gas) is recycled from the exhaust stack to the burner air intake, mixed with the incoming combustion air, and fed into the burner. The recycled ÿue gas consists of combustion products which act as inerts during the combustion of the fuel/air mixture. This serves to reduce the formation of NOx, by two mechanisms. Primarily, the recirculated gas acts as a dilutent to reduce the combustion temperatures, thus suppressing the thermal NOx mechanism. As a secondary mechanism, FGR also reduces NOx formation by limiting the amount of oxygen available for the dissociated nitrogen atoms to react with, because the majority of the oxygen in the ÿue gas has already been consumed by the initial combustion process. With this process, we are able to reduce NOx emissions by over 60 percent

A third method that may soon become an option to further reduce NOx emissions, employs the process of fuel staging. In this method, the fuel is divided into primary and secondary streams and injected into separate combustion zones. In the primary zone, fuel lean combustion reduces ÿame temperature. In the secondary zone, the oxygen depleted air from the primary zone prevents further NOx formation. This is typically a less economical solution, but with the combustion of fuel staging and external FGR, NOx levels can be reduced to meet and exceed even the most exacting local emissions standards.

Employing any one of these techniques also requires the use more sensitive control systems in order to ensure that the burner system is always running at the optimal efþciency. To achieve the most efþcient combustion th570044004F00ghoustencntuse s. By p. Tange teca giost stem is alway, we ha

Another technique that has been implemented by burner manufacturers, which we have found to be a very robust solution to reducing NOx emissions, has been the use of pre-mixed surface stabilized combustion burner designs. This method reduces the ÿame temperature through the use of excess air in the combustion gas. Typically, the implementation