ULTRA LOW NO_X GAS-FIRED BURNER WITH AIR PREHEAT

CARB Contract Number 94-354

Final Report

Prepared for
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November 23, 2000

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Leaders in Combustion Technology

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Acknowledgments

The authors wish to acknowledge the notable management of this project by Marla Mueller, Ralph Propper, and Manjit Ahuja of the Air Resources Board, Robert Gemmer and Isaac Chan of the Gas Research Institute, and Cherif Youssef of Southern California Gas Company.

The efforts of Kenneth Ahn, Ken Camino, Vladimir Lifshits, Steve Londerville, and Otto Maybauri of Coen Company in various phases of the program are gratefully acknowledged. The assistance of Jennifer Pont of Arthur D. Little (Acurex Environmental) is also acknowledged.

This report was submitted in fulfillment of ARB Contract Number 94-354 "Ultra Low NO_X Gas-Fired Burner With Air Preheat" by Coen Company under the partial sponsorship of the California Air Resources Board. Work was completed as of October 28, 1999.

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1.0 BACKGROUND

Industrial steam generators face increasingly stringent NOx emissions limits. As industry continues to expand, steam demands increase, requiring installation of new boiler equipment. In the United States, all new and modified boilers must install either Best Available Control Technology (BACT) or Lowest Achievable Emission Rate (LAER) technology depending on the attainment status of the region in which they are located. In California, only the term BACT is used, and its meaning is equivalent to the federal definition of LAER. At present, LAER (or California BACT) for NOx ranges from 7 to 12 ppm for industrial boilers, though regulatory agencies are pushing to reduce BACT to 5 ppm.

In 1998, California's South Coast Air Quality Management District (SCAQMD) made a BACT determination of 5 ppm for a new boiler at Fansteel Corporation. This emission level is based on the Cannon Low Temperature Oxidation (LTO) process. The LTO process is costly and consists of generating ozone and injecting it into hot flue gas to convert the NO to NO_2. The NO_2 is subsequently removed in a scrubber. Late in 1999, SCAQMD rescinded that determination and increased the allowable emissions up to 9 ppm. SCAQMD maintains that the LTO process is still viable, but that it wasn't suitable for the Fansteel application. Clearly there is downward pressure on NOx BACT for industrial boilers.

Until recently, the only way an industrial boiler could achieve single digit NOx emissions was through the use of costly selective catalytic reduction (SCR) in conjunction with a conventional low NOx burner. In the mid 1990's, a 9 ppm burner became commercially available, allowing new boilers to avoid the cost of SCR. However, it has had a history of trouble with stability and control. The market and the regulators needed a safe and reliable ultra low NOx burner (ULNB) that could compete with both SCR and the Cannon LTO process.

In 1995 Coen Company began work on a project to develop, demonstrate, and commercialize a novel gas-fired burner for large single and multiburner watertube boilers. The main objective for the new burner was to achieve 5 ppm NOx with wide stability limits. The Gas Research Institute and Southern California Gas Company funded the project, with considerable matching funds from Coen Company. In 1996, the California Air Resources Board provided Innovative Clean Air Technology (ICAT) funds to expand the scope of the project to include watertube boilers that either use air preheat or fire hot refinery gas. These boilers typically have more difficulty achieving low NOx emissions due to their relatively high combustion temperature, so the NOx goal for the air preheat portion of the project was 9 ppm. This report describes the results of the ICAT portion of the project.

The ICAT program performance goals for the industrial gas-fired ULNB were:

- NOx emissions at or below 9 ppm at 3 percent O_2 over all operating conditions with air preheat.

- CO emissions below 50 ppm at 3 percent O_2 over all operating conditions.
- Economic and commercial competitiveness with alternative technologies.
- Emission reductions obtained with efficiency, reliability and safety equivalent or better than conventional burners.

As will be demonstrated in the following pages, each of these goals has been met.

2.0 REVIEW OF TECHNOLOGY DEVELOPMENT WORK

The overall program consisted of development, demonstration, and commercialization of the new QLA burner. In the development phase of the project, computational fluid dynamic and kinetic modeling tools were utilized in conjunction with pilot scale experimental work to arrive at a prototype design. In the demonstration phase, the prototype burner design was scaled up, fabricated, installed, and evaluated at the Host Site. Since the ICAT program co-funded the second phase of this project, this report will focus on the demonstration effort.

2.1 Scope of Work

The demonstration phase of the project consisted of the following four tasks:

Task 1 - Host Site Search
The purpose of this task was to find an industrial boiler operator willing to retrofit the existing burners with the new Coen QLA burner. A list of required and desired boiler characteristics was formulated as shown in Table 2-1. Additionally, a copy of the CARB natural gas fired industrial boilers database was obtained. The Coen sales people reviewed the list of boilers and the selection criteria to come up with a short list of potential host site candidates. The candidates were approached with an offer including economic incentives unique to their site.

Table 2-1. Host Site Selection Criteria

Needs	Wants
Firing Rate 25 to 100 MMBtu/hr	Within California
Single Burner Design	Package Boiler
Ability to Test Entire Operating Envelope	No Superheat (b/c of increased FGR)
Air Preheat > 300°F	Sufficient FD Fan Capacity for FGR
	Air Preheat Bypass
	Acceptable Existing Boiler/Burner Controls
	Existing Coen Installation (Have Drawings)
	Willing to Cost Share

Task 2 - Regulatory Compliance
Initially this was a small task consisting of assisting with the permit application as needed. As will be described in Section 3, the actual effort required to comply with the Sacramento Metropolitan Air Quality Management District was quite large and unforeseeable. A delay in the construction process caused the backup boiler to be utilized more than allowed. A variance was granted for most of the excess utilization, but a violation was issued and settled for the few days before the variance application was filed.

Task 3 – Engineering, Fabrication and Installation

In Task 3, the burner concept developed in Phase I of the program was scaled up and retrofit onto the host site's boiler. The burners, windbox, fans, piping, ducting, dampers, and controls were designed/specified for the host site boiler by Coen Company. Following the design effort, Coen Company fabricated the burners, controls, piping, flue gas recirculation (FGR) inlet assemblies, and dampers at their site in Woodland, California. Fabrication of the windbox was outsourced. The new forced and induced draft fans were purchased by the host site and were installed along with the ducting by Combustion Associates Incorporated (CAI), the site's contractor. Coen Company hired Bay City Boiler to install the piping, windbox and burners. Regular meetings were held at the site to coordinate the design and installation activities. The installation was initiated in mid June and was nominally completed in July. Appendix A contains copies of the arrangement, flow diagram, burner assembly, windbox assembly, and other Coen Company engineering drawings.

Task 4 - Evaluation

To evaluate the performance of the newly installed QLA burner, pre-retrofit and post-retrofit tests were conducted. Stack emissions of criteria air pollutants were measured. Heat Loss Efficiency was quantified and fan power requirements were estimated and compared to the as-found condition. The cost of producing steam was calculated for as found and QLA operation.

3.0 RESULTS

The burner development work that took place in the first phase culminated in a full-scale demonstration at the State of California's Central Plant in Sacramento. Boiler 1, the main boiler, was chosen to be the demonstration boiler because the plant was not satisfied with the burners that had been installed by others in 1996 to comply with the 30 ppm NOx limit. Since the 1996 retrofit, the boiler had been load limited and was operating at reduced efficiency. A baseline test was performed in the summer of 1998 to document as-found conditions. The new QLA burners were installed in the summer of 1999 and a post-retrofit performance test was conducted in October of 1999. This section provides a description of the burner, a description of the boiler, and compares the emissions, efficiency, and steam production costs of operation with the QLA burners to pre-retrofit operation.

3.1 Description of the QLA Burner

Burner designs utilizing premixed natural gas combustion principles to achieve single digit NOx levels are no longer considered innovative. Applying these burners to industrial boilers safely with sufficient margins of stability, especially when the load modulates quickly over wide ranges, is the challenge. It is well known that industrial burners utilizing premixed combustion and high levels of flue gas recirculation (FGR) are prone to combustion driven pulsation which can result in loss of flame or mechanical damage. These pulsation regimes are dependent upon burner parameters such as firing rate, excess air, and amount of FGR as well as the acoustical response of the overall burner/boiler system.

The main function of the burner management system is to steer key parameters (excess air, FGR and fuel distribution) away from regimes that may develop pulsation or flame blow out. However, if the burner's operating range is too narrow, the control system will not be able to maintain it dynamically during load shifts, changes in environmental conditions or other disturbances. The competing commercially available ultra low NOx burner has had a history of flame-out and puffing, leading one to conclude that it has a very narrow margin of stability. In contrast, the QLA burner has demonstrated a wide margin of stability. The following paragraphs describe how the QLA burner design minimizes NOx emissions and provides for a wide margin of stability.

3.1.1 NOx Minimization Strategy

NOx in a natural gas flame is primarily formed via the thermal and prompt NO mechanisms. The key kinetic characteristics of thermal NO, also known as the extended Zeldovich reactions and prompt NO are illustrated in Table 3-1. The extended Zeldovich mechanism incorporates the in-flame interactions with $[OH]^-$ and $[O]^+$ radicals and post-flame reactions. Established nitrogen-methane-oxygen chemistry clearly points to maximum NO formation at peak temperature in the near stoichiometric region of diffusion flames. As suggested in Table 3-1, prompt NO denotes the rapid reaction of hydrocarbon radicals with nitrogen. The reactions are similar to fuel nitrogen conversion and exhibit much lower sensitivity to combustion temperature than thermal NO. The prompt NO reactions have a stronger influence at substoichiometric conditions.

Table 3-1. Important NO Formation Mechanisms.

Mechanism	Thermal NO	Prompt NO
Primary Reactions	$O + N_2 \rightarrow NO + N$ $N + O_2 \rightarrow NO + O$ $N + OH \rightarrow NO + H$	$CH + N_2 \rightarrow HCN + N$ $CH_2 + N_2 \rightarrow HCN + NH$ $CH_2 + N_2 \rightarrow H_2CN + N$ $C + N_2 \rightarrow CN + N$
Favorable Formation Conditions	High Temperatures Oxidizing conditions Time-at-Temperature	Fuel-rich early fame region
Adverse Design/Operating Condition	High volumetric heat release rate Air preheat Rapid fuel/air mixing Refractory surfaces	Diffusion flames (non-premixed conditions).

The formation of thermal NO occurs when the triple bond in atmospheric nitrogen in the combustion air is broken due to intense molecular vibrations at high temperatures. The nitrogen radical then reacts with oxygen to form NO. This reaction has a rate that is exponential with temperature and becomes excessive above temperatures of 3000F. Since prompt NO is a relatively small fraction of the total NO, the control strategy of the first generation low NOx burners was to reduce thermal NO. The traditional approach is to generate a long lazy flame that employs air staging and some degree of flue gas recirculation (FGR). Most of the combustion occurs under fuel rich conditions which suppresses temperatures, and the balance of the air is blended in relatively late when the temperatures are cooler. The FGR also serves to cool the flame and reduce thermal NO, but results in higher parasitic electricity use and can alter the radiant section heat absorption profile in the boiler.

The development of a gas burner that can reduce NOx to below 9 ppm requires suppression of both prompt NO and thermal NO. The conventional air staging approach encourages formation of prompt NO due to the fuel rich primary zone. Thus, an elegantly staged burner, which minimizes thermal, NO formation is inherently a prompt NO producer and is not the proper approach for an ultra low NOx design. An alternate approach is to premix the fuel with air to eliminate fuel rich pockets which promote prompt NO formation and to operate at relatively high levels of excess air and flue gas recirculation (FGR) to suppress flame temperature. Not only does this design approach minimize thermal and prompt NO; the absence of a fuel-rich region in the combustion zone inhibits formation of CO as well as VOC and toxic products of incomplete combustion, a concern for systems that employ air-staging techniques.

A schematic of the QLA burner is provided in Figure 3-1. The burner employs a large axially positioned bluff body, which serves to create a recirculation zone where ignition is sustained. The fuel, FGR and some of the air are premixed and flow through the outer passages, around the bluff body to the combustion zone. The balance of the air flows through the center of the burner. A small portion of the fuel can be diverted to outer gas spuds if required for stability.

Figure 3-1. QLA Burner Schematic

3.1.2 Burner Stability Considerations

Once the burner design showed the ability to emit extremely low levels of NOx, focus was concentrated on widening the margin of stability before the onset of pulsation. Pulsation in this burner occurs when the velocity of the mixture in the ignition region approaches the flame front propagation speed. The flame front propagation speed is heavily dependent on the amount of FGR, excess air and turbulent energy in the flow. The turbulent energy in the flow is proportional to the cubic root of the Reynolds Number while the load velocity is proportional to the Reynolds Number. Thus, with high velocity through the burner, the ratio between flow velocity and flame front propagation speed is high and combustion pulsation is not likely to develop even with wide variations in the FGR and excess air.

Conversely, pulsation is almost unavoidable as the velocity of the flow nears the flame speed. The velocity of flame propagation decreases as the adiabatic temperature of the combustion reduces with the increased amount of FGR or excess air. To avoid pulsation at low loads, the burner had to operate with even higher FGR or excess air to increase the mixture velocity. To combat stability problems at low loads, the design of the burner was altered to allow the bluff body to retract into the specially shaped burner throat to increase velocity of the fuel/FGR/air mix at low loads three fold.

3.2 Description of Host Site and Retrofit Activities

The QLA burner demonstration was conducted at the State of California's Central Plant in Sacramento. The plant is operated by the Department of General Services and consists of two 1950s era Combustion Engineering field erected boilers. The boiler's furnace is inherently high NOx producing as the floor and lower half of the four walls are all refractory lined and it is only 10 feet long. Boiler 1, the demonstration boiler, produces saturated steam which is used to heat and cool (through the use of steam driven chillers) 23 state government buildings in downtown Sacramento, including the Capitol. Boiler 1 in its as-found condition is shown in Figures 3-2 and 3-3. The boiler with the QLA burners installed is shown in Figures 3-4 through 3-7. Figures 3-4 and 3-5 are views of the boiler front wall showing the new burners, windboxes, and fuel trains. Figure 3-6 is a sideview of the boiler showing the new forced draft fan and FGR ducting. Figure 3-7 shows the new control cabinets and Figure 3-8 is a photograph of the flame at high fire.

The boiler design maximum continuous rating (MCR) is 60,000 pph of 250 psig saturated steam with an 80,000 pph five hour peak capacity. Up to 425°F preheated combustion air and FGR are supplied to two side-by-side burners by a forced draft fan. The burners fire horizontally at floor level with the combustion gases traveling up to the top of the furnace and then down through the steam generator. The gases leave the boiler at floor level, pass through the ljungstrom type preheater, induced draft fan, and finally exit through the stack. The existing burners employed FGR and steam injection to limit formation of NOx. An automatically controlled water injection system was subsequently installed to help maintain NOx emissions below the 30 ppm limit. The water and steam injection systems were removed as part of the retrofit scope of work.

The pre-retrofit test of Boiler 1 was conducted on June 30, 1998 and the results were subsequently documented and provided to CARB. The purpose of the test was to verify the as-found performance and emission characteristics of the boiler. The testing consisted of measuring emissions and quantifying heat loss efficiency at three loads (20, 40, and 50 kpph steam). For all test conditions, the air preheater was bypassed, the FGR damper was closed, and the water injection system was on.

On June 14, 1999, Boiler 1 was shutdown for the QLA retrofit. The scope of the retrofit included the burners, controls, fuel trains, and the combustion air and induced draft fans. In addition to the emission limitations, the plant required a wide turndown ratio and sufficient robustness to handle rapid load fluctuations. Traditional pneumatic controls with parallel positioning were selected to

Figure 3-2. Side-view of Boiler #1 prior to QLA retrofit.

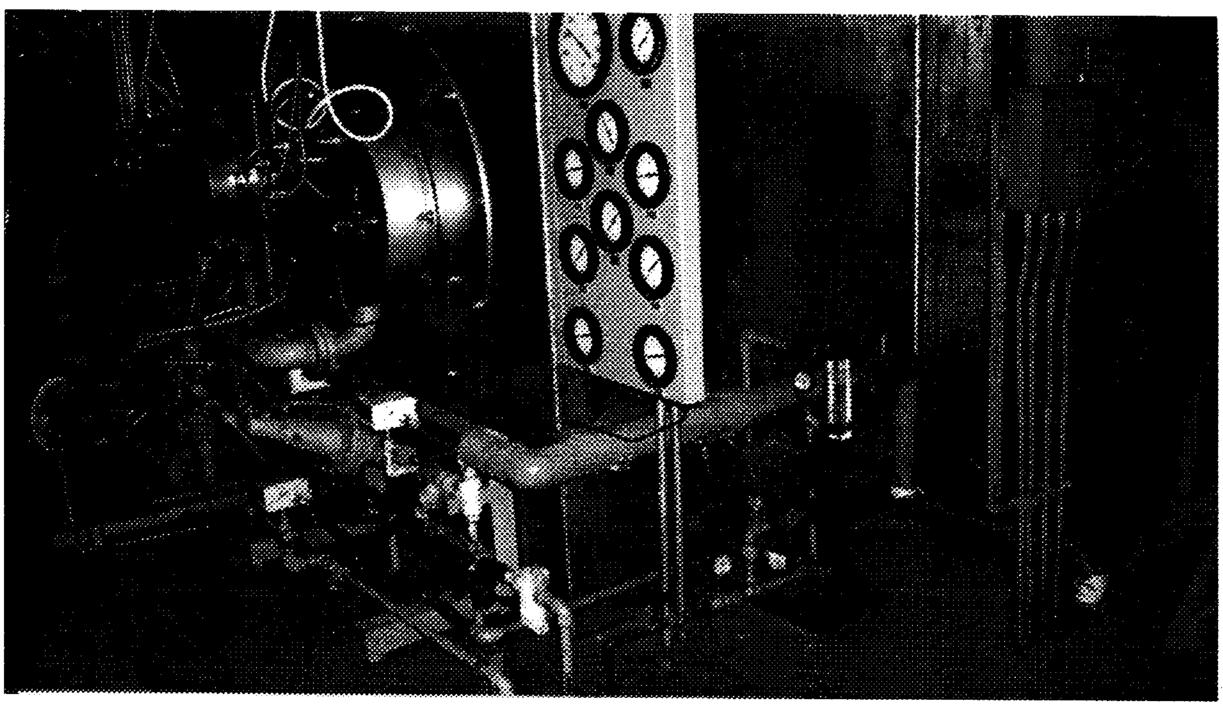

Figure 3-3. Boiler #1 windbox and burners prior to QLA retrofit.

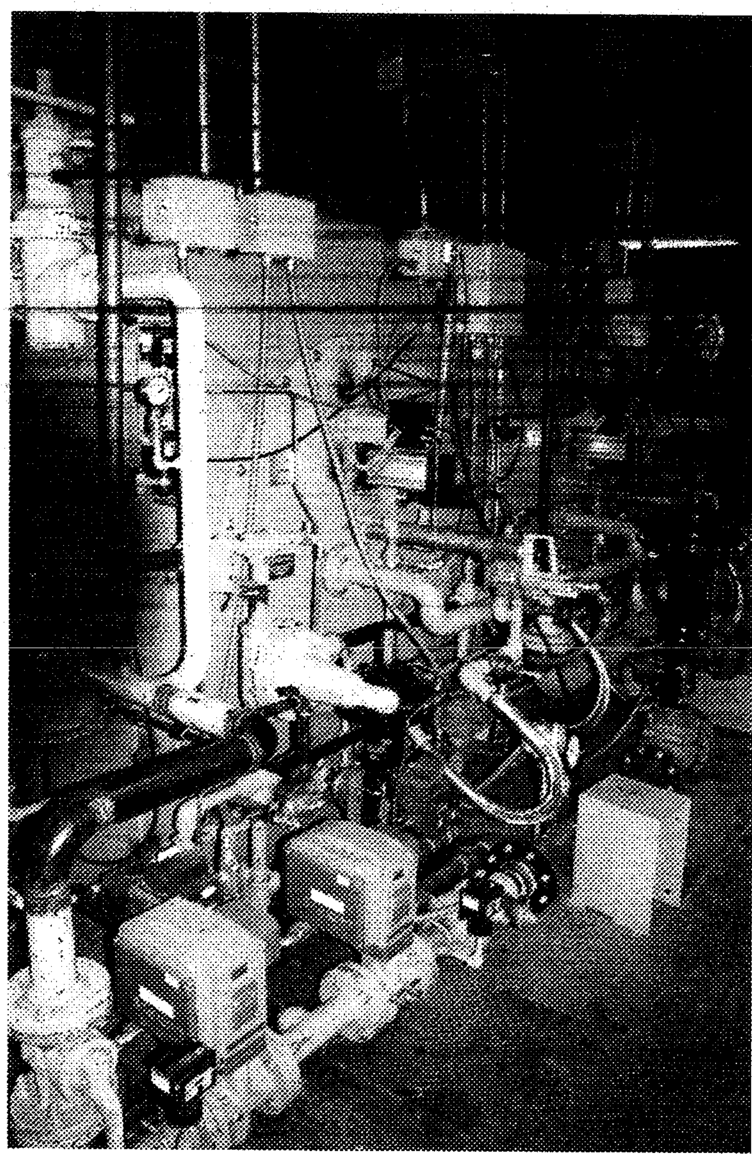

Figure 3-4. New burners, windbox and fuel trains at Central Plant.

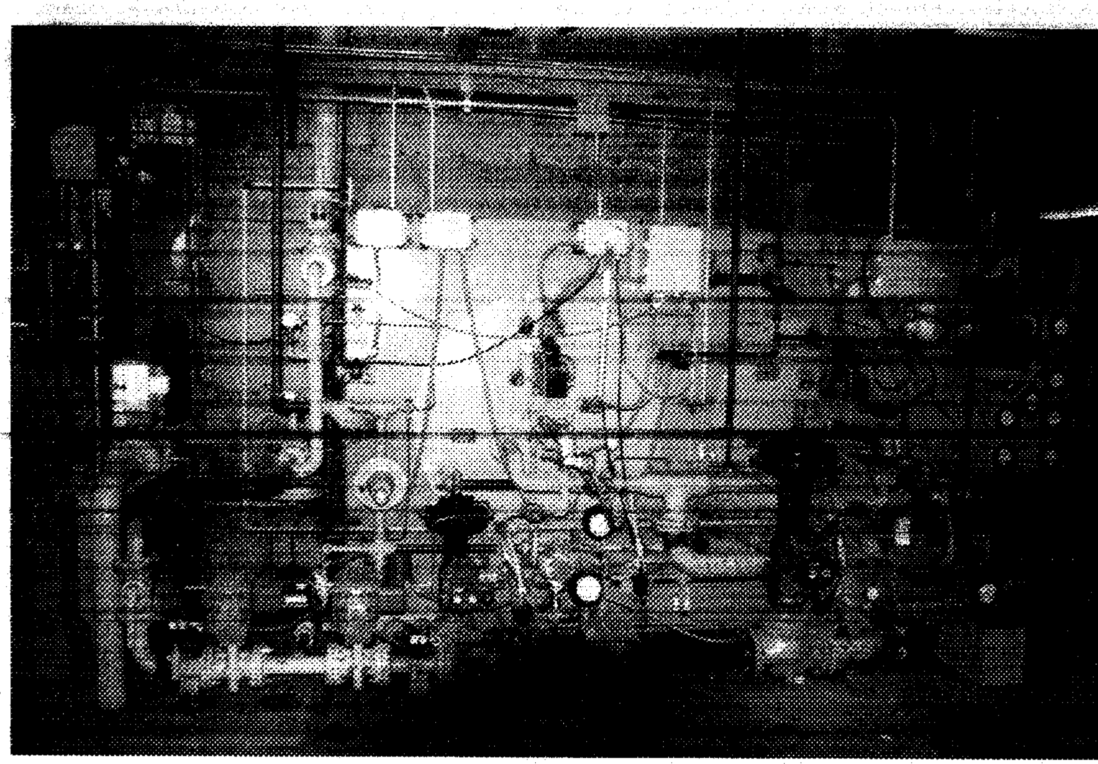

Figure 3-5. View of boiler front wall after QLA retrofit.

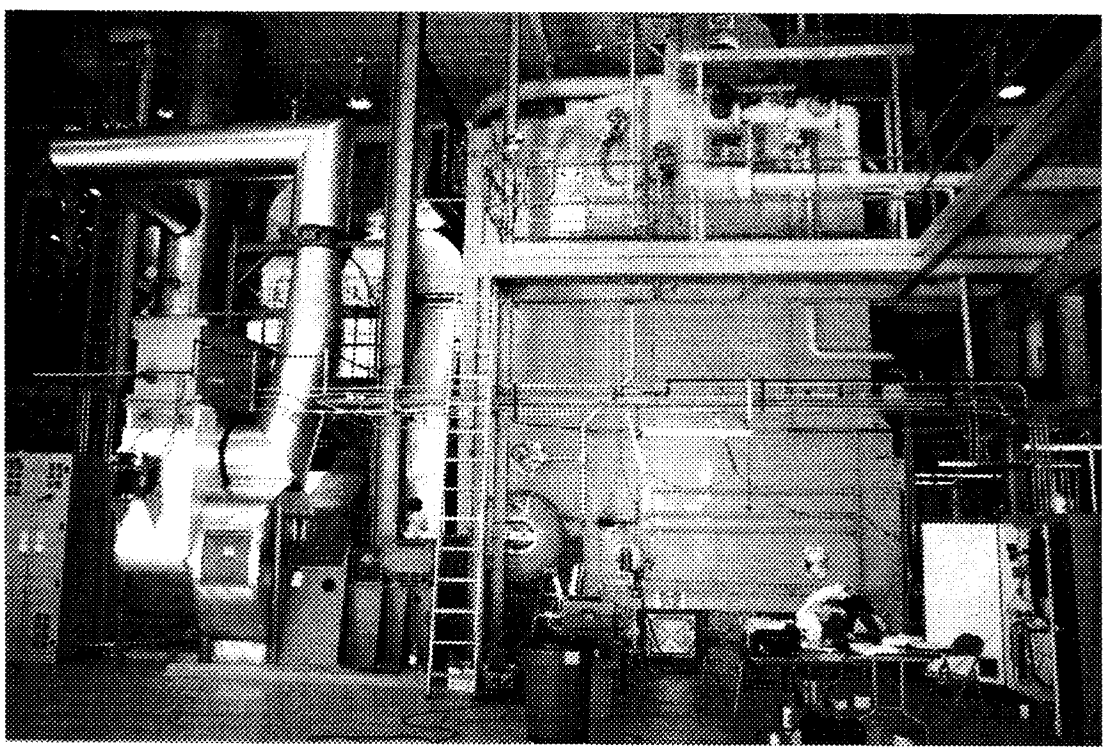

Figure 3-6. Boiler side-wall showing new FD fan and FGR ducting.

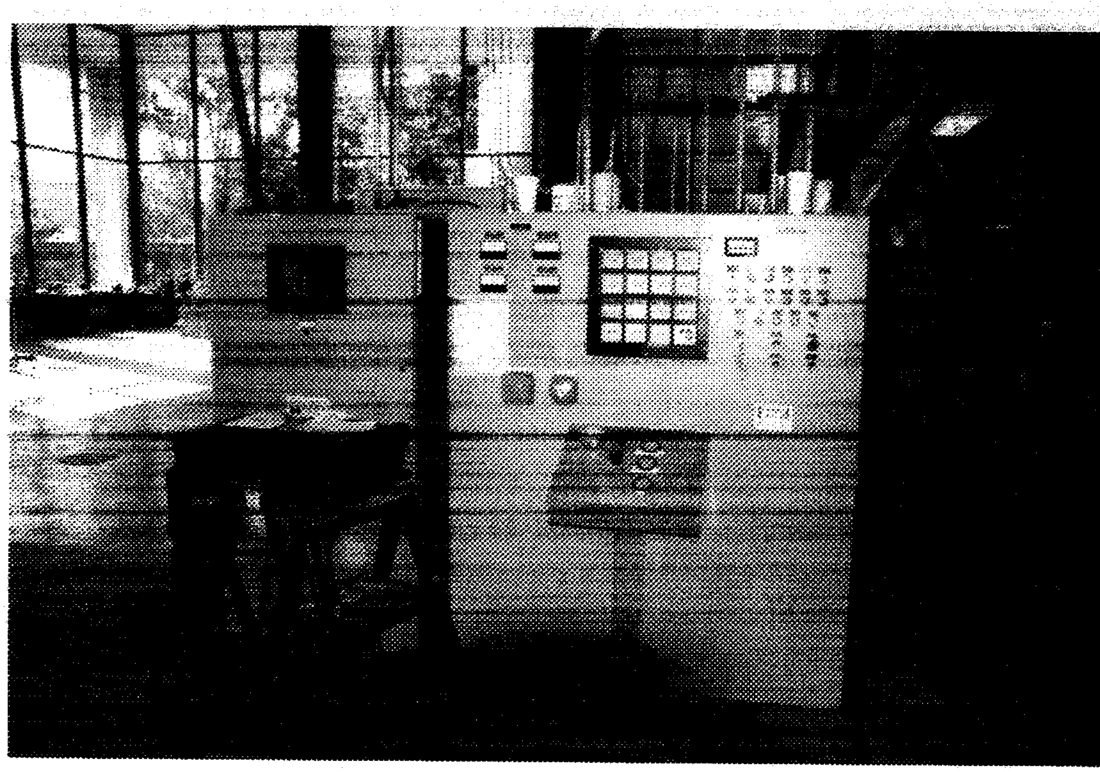

Figure 3-7. New control cabinets.

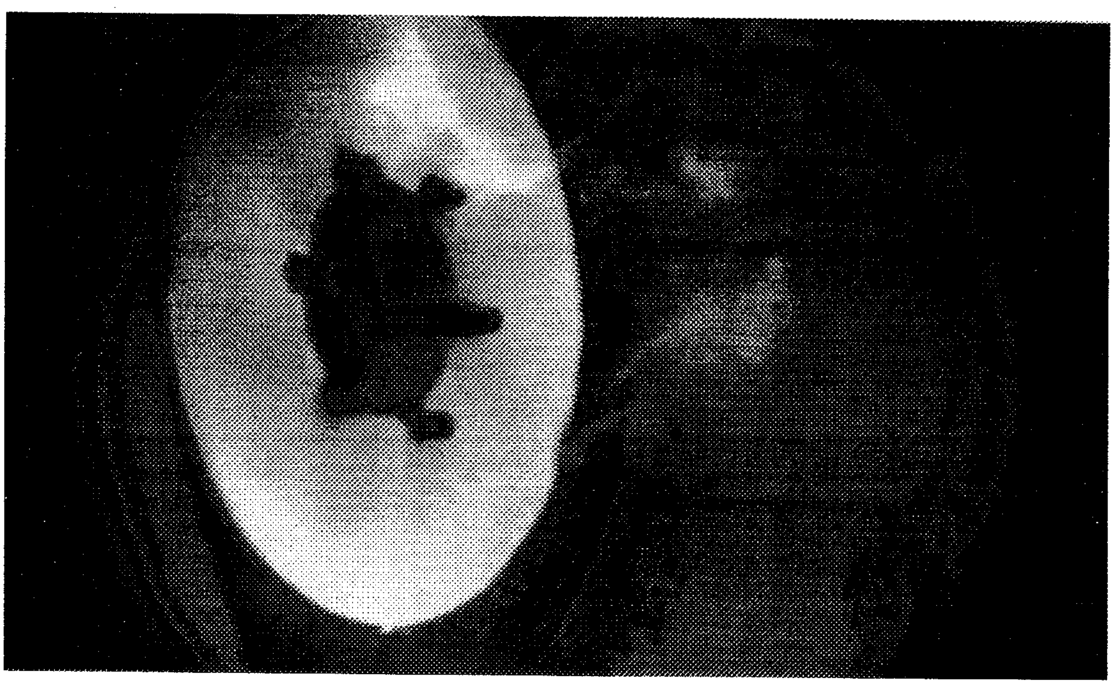

Figure 3-8. QLA flame from inside furnace at high fire.

ensure rapid response over a wide turndown ratio. Trim functions were applied to the combustion air fan variable speed drive to compensate for the variable environmental conditions and levels of air preheat. Position feedback modules monitored the performance of the actuators. The controls were governed by a new COEN 'Fyr-Monitor' system based on the Allen-Bradley SLC.

The outage was scheduled to last seven weeks so that Boiler 2, the backup boiler, would not fire more than its quarterly fuel allowance. Unfortunately, there were several unforeseen installation problems that delayed the startup of Boiler1 and subsequent shutdown of Boiler 2. The two main problems were the erroneous windbox drawings and a misunderstood scope of work by the site's contractor CAI. The windbox was actually two feet deeper than the drawings provided by the plant indicated, so a new windbox had to be designed, manufactured, delivered and installed. The gas lines had to be re-piped after the installation. CAI had not understood that their scope of work included the ductwork bringing the FGR to the FD fan. Because of CAI scheduling commitments, the ductwork could not be installed for one week. Other miscellaneous problems included:

- Damper positioners mis-wired at factory
- Fuel control valve feedback systems erroneously configured
- Existing wiring drawings not up to date
- Full day power outage - no testing

On August 4th, the backup boiler exceeded its quarterly fuel allowance. Although a variance was granted by the Sacramento Metropolitan Air Quality Management District Hearing Board, Coen and the plant decided to minimize excess emissions by postponing burner tuning until the beginning of the next quarter when the backup boiler could be legally operated again. As a result, Boiler 1 was put in automatic on August 20 at 30 ppm NOx and Boiler 2 was put into standby mode.

Final burner tuning was allowed to commence on October 4 and the post-retrofit test was conducted on October 28, 1999. Because this test also sufficed as the compliance source test, only the maximum load was tested. The test consisted of three 40-minute runs at an average steam load of 61,000 pph – a load that was not achievable with the as-found burners. In contrast to the pre-retrofit test, air preheat was utilized and resulted in an average combustion air temperature of 400°F. The Source Compliance Test Report may be found in Appendix B.

3.3 Emissions

The time averaged CEM data from the pre- and post-retrofit tests are presented in Tables 3-2 and 3-3. The data indicate that the excess O_2 with the QLA has increased, while the CO and NOx have both decreased. The post-retrofit emissions are 7.5 ppm of NOx and 3 ppm of CO (dry, 3% O2). During the post-retrofit test, excess O_2 and NOx were also monitored at the rear of the furnace. Assuming that there is no flow stratification and the single point measurement location is representative of the emissions at that point, NO may be formed well after the main combustion zone.

Table 3-2. Pre-retrofit Emissions Data

	Units	21,200 pph	Steam Flow 40,400 pph	51,700 pph
Stack Levels				
O_2	%	11.0	5.5	3.9
CO_2	%	5.6	8.9	9.2
CO	ppm, 3%O_2	0	3	15
THC	ppm, 3%O_2	0	0	0
Boiler Exit O_2	%	10.1	4.1	2.3

Table 3-3. QLA Post-Retrofit Emissions Data at 61,000 pph Steam

	Units	Run 1	Run 2	Run 3	Avg.
Stack Levels					
O_2	%	6.0	6.1	6.1	6.1
CO	ppm, 3%O_2	3.5	2.7	2.7	2.9
NOx	ppm, 3%O_2	7.3	7.6	7.6	7.5
Furnace					
O_2	%	4.6	4.6	N/A	4.6
NOx	ppm	3.1	3.0	N/A	3.1
NOx	ppm, 3%O_2	3.4	3.3		3.4

3.4 Burner Stability

The stable operating envelope of the burners at this installation was obtained as part of the controls setup process and is provided in Figure 3-9. The data were obtained by manually adjusting the air/fuel ratio at a variety of FGR levels and loads and visually verifying whether the flame was stable or entering the pulsation regime. The plot shows stable operation over a 10:1 turndown ratio and a wide range of stoichiometric ratio. In the year that the burners have been operating at the plant, there have been no reports of pulsation/flameout problems. The burners are operating safely and reliably.

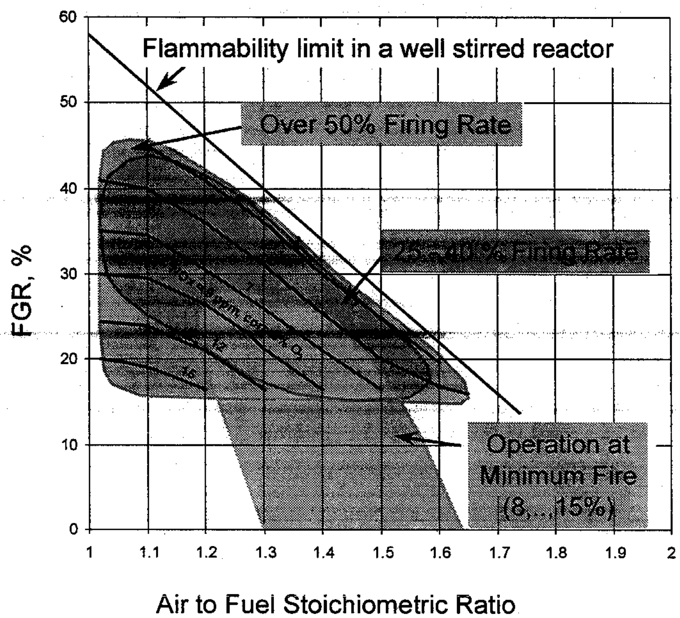

Figure 3-9. QLA Operating Envelope

3.5 Heat Loss Efficiency

Replacing burners generally does not significantly impact boiler efficiency. However, at Central Plant, the as-found burner/fan combination was so poorly engineered that the air preheater could not be utilized, and water injection was required to comply with the 30 ppm NOx limit. The QLA allows utilization of the air preheater and elimination of the water and steam injection systems, resulting in significant gains in boiler efficiency. The boiler's thermal efficiency for pre-retrofit and post-retrofit operation was calculated according to the ASME Heat Loss Efficiency Method. Losses due to dry gas, moisture from the combustion of hydrogen, moisture from water/steam injection, moisture from air, and radiation were quantified. The following data were used to calculate these losses:

- Fuel analysis and higher heating value
- Ambient air temperature, barometric pressure, and relative humidity
- Exhaust gas temperature at breaching between the Induced Draft (ID) fan and the stack
- Stack gas O_2, CO, and CO_2 content
- Water and steam injection flowrates

The fuel analysis was obtained from PG&E while the ambient temperature, barometric pressure, and relative humidity were obtained by calling the weather service periodically during the test. These values were also verified by A.D. Little instrumentation. For the pre-retrofit test, the stack gas temperature was recorded with a thermocouple and compared to the plant value recorded at the ID fan. The stack value was consistently 30°F cooler than the plant's ID fan value as would be expected. The plant ID fan value was used in the pre and post retrofit calculations. During the pre-retrofit test, the water injection flowrate was recorded from the plant's rotometer. The steam injection pressure was available, but not the flowrate. It was assumed that the steam flowrate was 15 percent of the water flowrate on a mass basis.

Table 3-4 presents the values of parameters used to calculate heat loss efficiency for the pre- and post-retrofit tests. The relative humidity during the post-test was significantly lower than the pre-test value; higher humidity reduces efficiency. Additionally, the exit gas temperature is considerably lower during the post-test because the air preheater was not bypassed. The resulting heat loss efficiencies are presented in Table 3-5. The average heat loss efficiency with the QLA burner at 61,000 pph steam is 78.1 percent. Even if the loss due to moisture in the air is disregarded, boiler operation with the QLA retrofit is a significant improvement over the as-found operation. The improvement is largely due to the elimination of water and steam injection as well as the use of preheated air.

Table 3-4. Heat Loss Efficiency Inputs

	Pre-Test			Post-Test		
	21,200	40,400	51,700	Run 1	Run 2	Run 3
Relative Humidity (%)	96	96	96	87	50	50
Barometric Pressure (in Hg)	30.01	30.01	30.01	30.2	30.2	30.2
Ambient Temperature (F)	67	74	82	67	67	67
Exit Gas Temperature (F)	502	562	602	441	439	437
Water Injection Flow (gpm)	0.4	2.1	2.8	N/A	N/A	N/A

Table 3-5. Heat Loss Efficiency During Pre- and Post-Tests

	Pre-Test			Post-Test		
	21,200	40,400	51,700	Run 1	Run 2	Run 3
Loss Due to:						
Dry Gas	14.5	10.2	10.5	8.5	8.6	8.5
Fuel H_2 Moisture	11.8	12	12.1	11.5	11.5	11.5
Water/Stm Injection	0.6	2.2	2.5	N/A	N/A	N/A
Moisture in Air	2.4	2.1	2.5	1.5	0.9	1.1
Radiation	1.8	1	0.8	0.8	0.8	0.8
Heat Loss Efficiency	68.9	72.6	71.6	77.7	78.3	78.4

3.6 Fan Power Consumption

Because the amount of FGR is increased with the QLA burner from approximately 10 percent to 38 percent, both the forced and induced draft fans had to be replaced with larger models. Fan power consumption for the existing and retrofitted fans was estimated from the fan curves. These curves provide horsepower and static pressure as a function of flowrate for a given speed. Because these are variable speed fans, they operate at different speeds for each test condition. A new fan curve can be generated for each fan speed by scaling the test block data with specific speed, a dimensionless parameter. Hence, for each test condition (rpm), a scaled fan curve is generated, and the power can be read from the new curve. Fan speed was not provided on the fan readout, so it was determined by scaling with one of the fan laws ($RPM_2 = Flow_2/Flow_1*RPM_1$).

Table 3-6 presents the results of the fan power analysis. Flow rates, fan speed and the resulting motor power are provided for pre- and post-retrofit operation. Fan motor mechanical efficiencies for the new FD and ID fans were 85.6 and 84.9 percent respectively. Fan motor mechanical efficiency for the as-found fans was assumed to be 85 percent. As may be seen from the table, total fan power for QLA operation is more than twice the pre-retrofit level. The increased fan power consumption is due to the 20 percent higher test load and the increase in FGR from 10 percent to 38 percent.

Table 3-6. Pre-retrofit and QLA Fan Power Consumption

		Pre-Retrofit	QLA
Steam Flow	pph	51,700	61,283
FD Fan			
Flow	acfm	17,303	24,873
Speed	rpm	1306	1554
Motor Power	hp	34	92
ID Fan			
Flow	acfm	32,526	39,673
Speed	rpm	1837	1475
Motor Power	hp	57	124
Total Fan Power	hp	91	216

3.7 Reduction in Operating Cost

Because the retrofit project improved boiler efficiency so dramatically (mainly due to the elimination of water injection and the use of air preheat), significant fuel savings will be realized by the plant, which more than offsets the increased fan power costs. Table 3-7 provides a comparison of fuel and fan power costs for pre- and post-retrofit operation. The analysis uses the Central Plant fuel cost of $2.70 per million Btu and a cost of purchased power of $0.075 per kWh. At maximum load, the QLA provides cost savings of $0.35 per 1000 lbs of steam generated. Although a post-retrofit test at lower loads was not conducted, we have estimated the fuel and fan power use for these conditions as well. If the boiler is operated at each of the three loads for one third of the time (e.g.365*24/3 = 2920 hrs), the plant could expect to save approximately $116,000 per year.

Table 3-7. Fuel and Fan Power Costs

	Low Load	Mid Load	High Load
As Found Operation			
Steam Flow, kpph	21.2	40.4	51.7
Fuel Cost, $/hr	83.6	151	196
Fan Power Cost, $/hr	2.2	3.3	5.1
Steam Cost, $/1000#	4.05	3.83	3.89
QLA Operation			
Steam Flow, kpph	21.2	40.4	61.3
Fuel Cost, $/hr	74	140	205
Fan Power Cost, $/hr	1.7	5.7	12.1
Steam Cost, $/1000#	3.59	3.60	3.55

3.8 Summary of Regulatory Compliance Efforts

DGS operates two boilers to supply steam to its customers. The new burners were installed on Boiler 1, which had previously been retrofit with unsatisfactory 30 ppm low NOx burners in compliance with SMAQMD Rule 411. An installation permit was granted; the source was deemed exempt from New Source Review requirements (LAER and offsets) because the replacement equipment exemption was invoked, and potential emissions decreased. The SMAQMD replacement equipment exemption was being challenged by EPA Region IX at the time of the application. A determination was requested and received from Region IX allowing the plant to utilize this exemption since it is a minor source.

During the 9 ppm retrofit on Boiler 1, Boiler 2 was slated to carry the entire heating and cooling load for the 23 government buildings that it serves, including the state capitol. Boiler 2, the backup boiler, complied with the 30 ppm limit via Rule 107, Alternative Compliance. The plant shutdown several gas turbines and applied the resulting emission reduction credits to Boiler 2's RACT limit. The result was a quarterly fuel limit for Boiler 2. To maximize the length of Boiler 1's outage (Boiler 2's fuel allowance), the retrofit was planned to straddle the second and third quarters. Boiler 2 was not utilized in the second quarter until the retrofit began in mid-June. The second quarter allowance was not exceeded. The retrofit continued as scheduled into the third quarter when the installation problems previously discussed occurred. The problems extended the Boiler 1 outage period and as a result, Boiler 2 was utilized more than originally planned.

On August 3, Boiler 2 exceeded it's third quarter allowance and the plant submitted a variance petition on August 6. The delay was caused by the time it took the government to write a check, and SMAQMD would not accept a credit card. After two hearings with testimony coordinated by Coen Company and A.D. Little, a variance was granted to cover excess fuel usage on Boiler 2 from August 6, 1999 through September 30, 1999. As a condition of the variance, DGS was required to purchase and surrender 1336 ERCs corresponding to the estimated number of excess pounds of NOx emitted during the variance period. A notice of violation was subsequently issued for the three days, which were not covered by the variance corresponding to the start of the violation on August 3 and the submittal of the petition on August 6. The notice of violation was settled when the plant agreed to pay a fine.

4.0 Description of the Technology Developed and its Status

The objective of the ICAT project was to install the QLA burner on a boiler utilizing air preheat and demonstrate stable operation with NOx emissions below 9 ppm. The QLA burner was installed at the State's Central Plant in Sacramento, California during the summer of 1999. During the compliance source test NOx and CO emissions were 7.5 ppm (dry, 3% O_2) and 3 ppm (dry, 3% O_2), respectively. The combustion air temperature was 400°F. The steam flow turndown ratio is 10 to 1 and the burner is stable over a wide range of excess air levels and FGR flow. Perhaps most importantly, the customer is extremely happy with the performance of the burners over the past year, and wants to install them in the new boiler that he is planning to build. The QLA burner is now considered a commercial product, and Coen Company will guarantee NOx emissions of 9 ppm. Coen Company is currently developing an advanced burner control system, which will allow for a 5 ppm guarantee. This section describes the QLA burner advantages and operational limits. The competing technologies are described, costs are compared, and the potential market size is estimated.

4.1 QLA Burner Capabilities and Limitations

The QLA burner utilizes premixed combustion; the fuel is ignited after it has been uniformly mixed with the combustion air and a large amount of FGR. This approach substantially reduces prompt NO formation by eliminating local fuel rich areas. Thermal NO formation is minimized because FGR reduces flame temperature. Burners utilizing high levels of FGR typically have narrow margins of stability with respect to deviations in the stoichiometric ratio and the rate of FGR. The narrow margins make it more difficult for the control system to prevent operation in regimes that may lead to combustion driven pulsation. If the boiler/burner system enters into pulsation, it can result in an explosion or flameout.

While the development of the QLA burner took over two years to complete, the majority of the effort was directed toward making the burner more robust with respect to variations in stoichiometry, FGR flow and ambient conditions and less sensitive to the inaccuracy of the control system. This was especially important at lower loads where correct ratios between the flows are more difficult to achieve. The resulting burner design utilizes both premixed combustion and a small degree of fuel staging. The burner has an optional variable geometry, which addresses the turndown issue and operates with low excess air and practically no CO emissions. Coen Company will presently guarantee the QLA burner at 9 ppm with conventional control technology. Coen Company will only guarantee 5 ppm if the site also installs its developing advanced combustion control system. In summary, present technology is 9 ppm with near future guarantees of 5 ppm.

4.2 Competing Technologies

This project has provided industrial watertube boiler operators with a safe, reliable, lower cost option to comply with current and future regulatory constraints. The two other technologies that achieve the same level of NOx emissions are: selective catalytic reduction (SCR) and the Cannon Low Temperature Oxidation (LTO) process. SCR systems consist of injecting ammonia in the exhaust gas and flowing the mixture over a catalyst bed to convert NO to molecular nitrogen. SCR is expensive and has environmental liabilities. Storage of large amounts of ammonia is dangerous and is increasingly encountering negative public comment in the permitting process. In addition, byproduct and fugitive ammonia emissions cause secondary particulate formation. Finally, the spent catalyst is considered a hazardous waste.

The Cannon LTO process consists of injecting ozone into the exhaust gas to convert NO to NO_2. The water soluble NO_2 is subsequently removed in a wet scrubber. The process is extremely expensive because it requires construction of an ozone generation plant and a scrubber. Ozone is a hazardous substance, and the aqueous scrubber waste may require a discharge permit. This technology has not been widely accepted.

An estimate of the costs of a QLA retrofit compared to an SCR installation is provided in Table 4-1. The analysis assumes a 100 MMBtu/hr boiler operating at an annual capacity factor of 50 percent. . The interest rate was assumed at 10 percent and the equipment life was estimated at 20 years. The burner hardware cost includes a new FD fan, new controls, and the FGR ductwork and inlet box. The annualized capital cost for the QLA burner is approximately 60 percent of the cost of SCR.

Table 4-1. Comparison of QLA and SCR costs.

Cost Item	Units	QLA	SCR
Capital Costs			
Hardware Costs	$	170,000	382,000
Installation Cost	$	68,000	286,591
Installed Capital Cost	$	238,000	668,591
Annualized Capital Cost	$/yr	27,955	78,532
Operating Cost			
Increased Fan Power	$/yr	35,000	
Catalyst	$/yr		21,600
Ammonia	$/yr		1,173
Total	$/yr	35,000	22,773
Total Annual Cost	$/yr	62,955	101,305

4.3 Estimate of Market Size

Regulatory pressures drive the market for this burner. The two possible drivers are BACT/LAER for new sources and new rules for existing sources. New boilers are required to install either BACT or LAER for NOx control depending upon the ozone attainment status of the region where the boiler is located. At present, BACT and LAER are SCR down to the 8-12 ppm range. Since the QLA is a lower cost option, it can be assumed that many new boilers will select the QLA as BACT/LAER. The American Boiler Manufacturer's Association (ABMA) projects that approximately 100 new watertube package boilers will be installed each year for the next five years in the United States. If we assume that half of these select the QLA as BACT/LAER, then Coen Company can expect approximately 50 orders per year.

In addition, The Texas Natural Resource Conservation Commission has recently proposed a new rule for the Houston/Galveston area that limits NOx from existing industrial boilers to 8.2 to 12 ppm, depending on boiler size as shown in Table 4-2. The comment period for the draft rule closed in October 2000, and it should be promulgated in early 2001. Implementation of the new limits was proposed to be phased in between Dec 31, 2002 and Dec 31, 2004. Assuming that the rule is promulgated and that half of the boilers select the QLA burner, an additional 135 burners would be sold in the next three years.

Table 4-2. Houston/Galveston Proposed Rule

Boiler Size	Proposed Limit ppm (3% O2)	Number of Boilers
> 100 MMBtu/hr	8.2	180
40 -100 MMBtu/hr	12	90