

# **GAS COFIRING FOR PERFORMANCE IMPROVEMENT AND EMISSIONS REDUCTION IN COAL AND WOOD-FIRED BOILERS**

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## **ABSTRACT**

Cofiring a small amount of gas in solid-fuel fired boilers is an efficient and economical way to resolve a variety of emissions and performance problems. Gas Research Institute has developed and demonstrated a specialized cofire retrofit package featuring dual, opposed high pressure drop gas burners to control the combustion over the solid fuel. Earlier demonstrations on coal-fired stokers have shown cofire to reduce emissions, enhance performance, increase efficiency and lower operating costs. In the present work, the cofire package has been applied to two coal and two wood-waste fired industrial boilers. At the first coal site, cofire reduced particulate up to 60 percent for 20 percent gas firing. At the second coal site, gas cofire was used to reduce NO<sub>x</sub> emissions by 20 percent for 20 percent cofire. For wood firing, the strongest driver for gas cofire is to correct for performance degradation caused by wet wood. At the two sites, gas cofire in the 10 to 15 percent range gave recovery of lost capacity derate and up to 90 percent reduction in carbon monoxide emissions.

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## COFIRE TECHNOLOGY

United States industry operates over 2000 solid-fuel fired boilers for process steam, space heating and cogeneration. The majority are coal and wood-fired stokers, with a significant but smaller population of stokers fired with combustible wastes or mixed fuels, as well as non-stoker firing types, such as fluidized beds and pulverized coal. The fixed bed method of firing used in most solid-fuel industrial boilers can introduce severe operational and environmental constraints. The solid-bed method of combustion is prone to smoking and is typically slow to respond to load changes. The boiler efficiency is lower than with other firing types because of high levels of excess air used to suppress incipient smoking, and high carbon loss in ash. Despite these challenges, it is important to industry to maintain and, if possible, enhance the capability of the stoker resource base.

Gas cofiring has been attempted sporadically over the years to address operational limitations with coal and wood-waste fired boilers. The results with these early gas burner retrofits was mixed. Typically, the gas flame was not engineered to interact with the solid-fuel combustion, but merely to be a startup and standby source of heat. Accordingly, the benefits achieved with gas cofiring were often modest and not necessarily keyed to the most important site-specific economic drivers for the plant. Also, in the early applications, conventional low pressure register burners were used. These sometimes operated off the existing forced draft fan and had weak penetration into the boiler flame and also very limited turndown. An additional complication was that the burners were usually placed high in the furnace over concern of grate overheating. The combined characteristics of low penetration, low turndown, and remote placement usually relegated the use of the burner to warmup and standby.

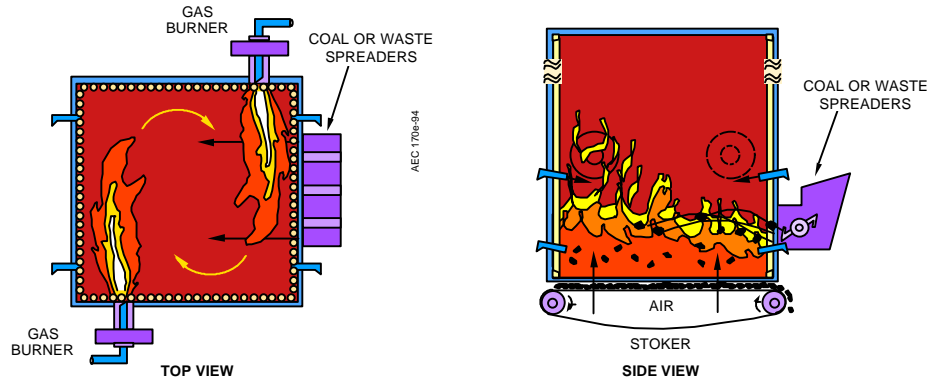
In 1994, Gas Research Institute formed a team of ARCADIS (formerly Acurex Environmental), Coen, gas utilities and boiler operators to develop and implement gas cofire for coal-fired stokers. The basic objective was to use gas as a process modification to resolve combustion problems with solid-fuel fired boilers. In this way gas was introduced as a value-added combustion enhancement, rather than as a replacement fuel to the cheaper solid fuel.

At the start of the project, surveys with over 50 boiler operators showed that the industrial boiler sector was coping with a variety of performance and environmental problems. The most prevalent problem was opacity control which was strongly linked to attempts to obtain high and low-load turndown, or routine load swings. Other major issues were coping with fuel variability and achieving environmental compliance. To address these operational issues, a cofire hardware package was developed by Coen Company and the project team.

The criteria for the new cofire system was twofold:

- Achieve maximum operating benefits from a small amount of gas, typically 5 to 15 percent of total heat input,
- Design a flexible package readily adaptable to a wide variety of stoker designs and to a diversity of desired benefits

The basic cofire system which has been developed and used since 1994 is shown on Figure 1.



**Figure 1. Cofire System.**

The cofire system features dual, opposed, offset, high-pressure drop burners with an integral forced-draft fan for each burner. The 10 inch pressure drop is essential to give 5 major benefits:

- Enhanced mixing in the firebox via deep flame penetration into the solid fuel combustion gases and due to the torroidal mixing pattern
- Strong swirl in each individual flame which gives local mixing and entrainment of combustion products into the gas flames
- Small burner throat diameter giving easy access, placement flexibility and minimal interference with watertubes
- Large burner load turndown, typically 10:1, to permit performance at low cofire or as a stand-alone start-up or standby burner
- Wide stoichiometry range for operation at high excess air levels, effectively acting a overfire air, or at fuel rich conditions for NO<sub>x</sub> control

These features give an independently controlled gas combustion zone, but one which intensely interacts with the solid-fuel fired flames.

The cofire burner concept was to use a standardized burner hardware configuration, to reduce site specific custom engineering and fabrication, but to retain sufficient site specific flexibility to allow coverage of a variety of operating modes. The burner parameters which can be specified to meet site specific performance goals are:

- Burner capacity
- Burner throat diameter and geometry
- Burner placement: separation and height above grate
- Swirl
- Gas injector design

These hardware parameters are selected based on the ensemble of benefits sought from cofiring, as describe in the next section.

## **BENEFITS**

The cofire burner hardware is specified to give the broadest coverage of benefits for the specific boiler design and plant economic characteristics. Surveys of candidate cofire sites have shown that a given site may draw on several benefits from cofire, and that the choice of which benefits are dominant is highly site specific. The benefits achievable with cofire are very diverse:

### **Performance Enhancement**

- Wide load turndown
- Quick response to load changes
- Recovered derate
- Reduced excess air
- Enhanced carbon burnout
- Eliminate need for backup units
- Increased efficiency
- Fast cold iron startup
- Ability to stay on spinning reserve

### **Environmental Compliance**

- Eliminate opacity spikes and reduce time average opacity
- Reduced particulate emissions
- Reduced fine particulate, PM<sub>2.5</sub>, emissions
- Reduced load on dust collectors
  - Increased collector efficiency due to reduced fine particulate
- Reduced NO<sub>x</sub> emissions
- Avoided cost of emissions control devices or control upgrades
- Reduced CO emissions with wet fuel

### **Fuel Flexibility**

- Wider latitude with fuel quality specifications
  - Fines
  - Sulfur
  - Moisture
- Seasonal gas use
- Backup for solid fuel feed interruption

### **Operational Improvements**

- Reduced slagging and maintenance
- Extended lifetime

Each of these benefits translates into operating cost reductions depending on the plant fuel costs, environmental compliance status and operating constraints. To achieve the desired economic benefits, the burners are tuned and set during startup to maximize the boiler response for the specific group of benefits selected by the site. Parameters selected during field optimization are:

- Cofire rate vs. boiler capacity
- Burner stoichiometry: excess air level for various gas burner firing capacities
- Cofire burner front-to-back biasing
- Automatic gas burner control for load following

Typically, the composite economic benefits for a cofire retrofit will payback the cofire hardware and installation capital costs in 1 to 3 years.

Starting in 1995, three coal-fired boilers were selected for initial evaluations: Dover Light and Power, Hoover Company, and Oberlin College (References 1 and 2). These retrofit projects quantified the benefits of cofire for both spreader and mass-feed chain grate coal-fired stoker units with diverse coal types and operational constraints. Specific operational benefits demonstrated included: recovered derate, reduced particulate, extended low load turndown, rapid load following, quick, clean lightoffs, and increased efficiency. On the basis of these technology validations, GRI extended the program to a broader range of coal-fired applications, and to the wood-fired boiler population.

## **TEST PROGRAM**

Starting in 1996, GRI initiated additional field evaluations of cofire for coal-fired stokers and started field evaluations for wood-waste fired units. The purpose of the coal-fired field programs was to extend and validate the cofire technology for additional boiler designs and cofire benefits. Two sites tested under this effort, Ford Motor Company, Cleveland Engine Plant, and the Capitol Power Plant in Washington D.C. are discussed in this paper. The purpose of the wood-waste fired field program was to transfer and adapt the cofire technology from the coal-fired stokers to the wood-fired units. Two sites tested under this effort, Boise Cascade, Emmett Idaho, and Washington Water Power, Kettle Falls, Washington are discussed in this paper.

### **Ford Motor Company**

Ford Motor Company owns and operates six coal-fired stoker boilers at its Brookpark engine manufacturing facility in Cleveland, Ohio. These boilers have a total steam generation capacity of 500,000 lb/hr with a combined heat input rating of 650 MMBtu/hr. In this project, Ford and East Ohio Gas teamed to retrofit the Boiler No. 5 Riley-Union spreader stoker with dual Coen CoFyr burners. The boiler has a design capacity of 100,000 lb/hr but has been derated to 70,000 lb/hr to meet opacity and particulate emissions limits.

The two primary drivers at Ford for gas cofire were:

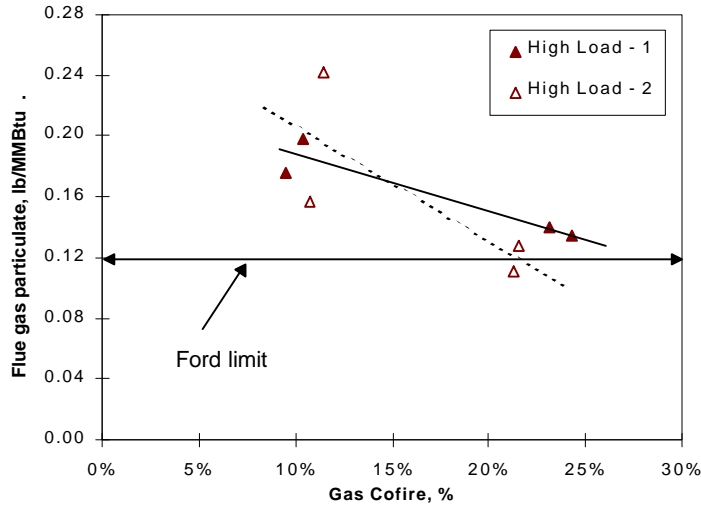
- Recovery of lost derate caused by excessive particulate emissions at high load
- Ability to fire 100 percent gas during summer months when plant demand is low, thereby reducing operating costs normally associated with solid fuel firing.

To strike the best balance between these two objectives, the gas burners were sized at 65 MMBtu/hr total heat input. This capacity was sufficient to operate the boiler at 50 percent capacity on gas alone. To achieve best flame shaping for both low and high gas burner firing capacities, different gas spuds were used for low capacity cofire and high capacity seasonal gas use. Other secondary benefits included clean startups, extended low-load turndown, and increased efficiency.

The boiler was retrofit with cofire burners in October, 1997 and subjected to a series of performance and environmental tests in December. The testing consisted of continuous monitoring for O<sub>2</sub>, CO, CO<sub>2</sub>, and NO<sub>x</sub>, EPA Method 5 for particulate, Andersen impactor train for particle sizing, grab samples for fuel feed and ash

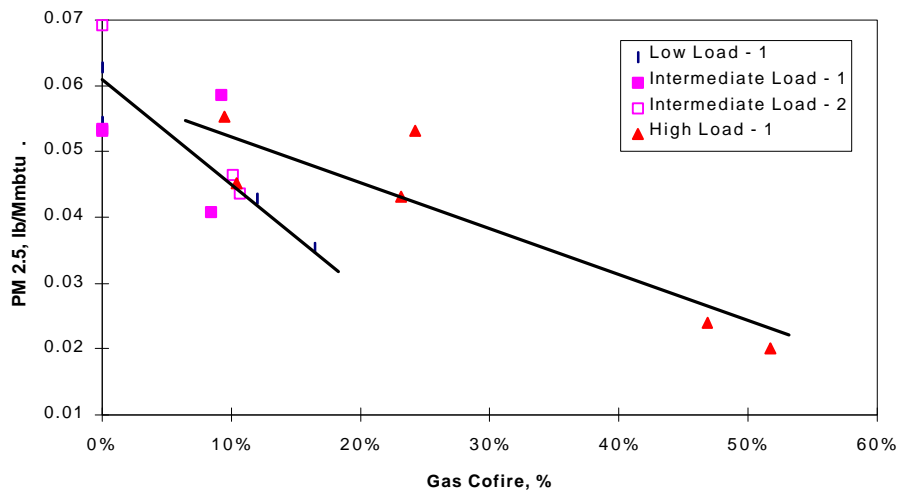
streams, and process data. The burner swirl vanes and gas spuds were changed to achieve broader coverage of the dual objectives cited above, and the tests were repeated in April, 1998.

Figure 2 shows the response of boiler particulate emissions to gas cofire at high load. These data showed that with about 20 percent gas cofire, the 30 percent lost capacity derate could be recovered with acceptable particulate emissions.



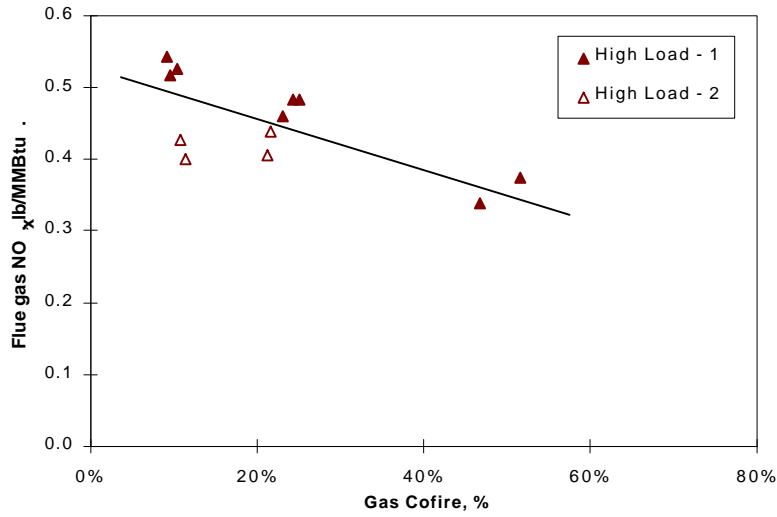
**Figure 2. Ford Total Particulate Emissions.**

Results also showed that fine particulate were reduced with cofire. This benefit is of increasing importance as regulatory groups are considering ambient standards for PM<sub>2.5</sub> as a result of the recent revision to ambient air quality standards. Figure 3 shows a consistent reduction in fine particulate across the load range of the boiler. Part of this reduction may be due to enhanced carbon burnout of the flyash with cofire.



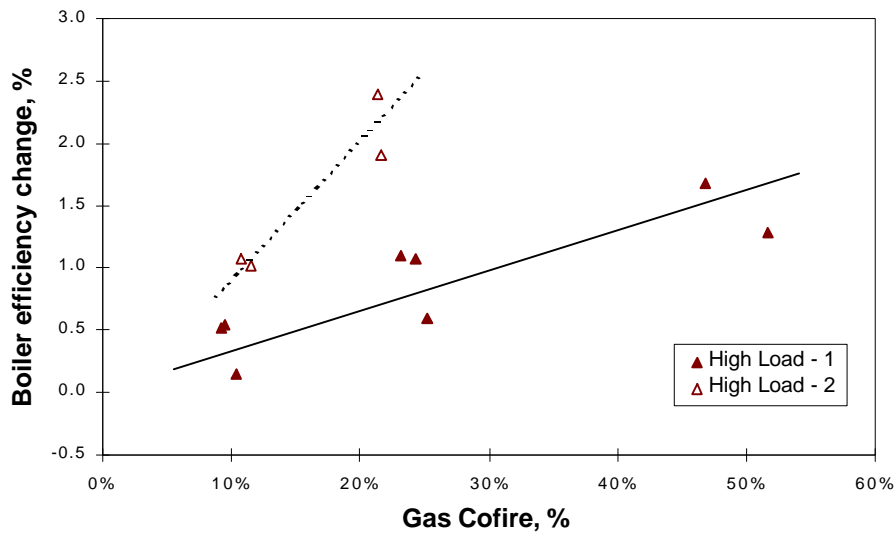
**Figure 3. Ford Fine Particulate Emissions.**

Reduction in NO<sub>x</sub> emissions was commensurate to the displacement of the coal by gas, Figure 4. Since particulate reduction was the primary objective, no attempt was made to fire the gas burners fuel rich to minimize overall NO<sub>x</sub> from the coal and gas flames.



**Figure 4. Ford NO<sub>x</sub> Emissions Results.**

Overall boiler efficiency generally increased with cofire due to reduction in excess air level and generally improved carbon burnout in flyash. Figure 5 shows the efficiency response to cofire for the two burner configurations for full load. This efficiency decrease was consistent with a reduction in excess oxygen of about 1.5 percent for 20 percent gas cofire.



**Figure 5. Ford efficiency Results.**

Other benefits of cofire at Ford included extension of the low load turndown from a previous minimum capacity of 40,000 lb/hr to 25,000 lb/hr with cofire. SO<sub>2</sub> emissions were also reduced proportional to the displacement of the coal.

### Capitol Power Plant

To heat the nations Capitol and associated buildings, the Capitol Power Plant operates two 160,000 lb/hr Wickes coal-fired spreader stoker boilers. The typical maximum steaming rate for the coal-fired stoker units is 120,000 lb/hr. One of the boilers was retrofit with dual Coen CoFyr burners in December, 1997, and tested in February - April 1998. The combined firing capacity of the gas burners was 60 MMBtu/hr.

The primary incentive for the gas cofire system was to trim NO<sub>x</sub> emissions. A secondary objective was to give faster cleaner lightoffs and rampup to full load. The boiler was tested across the nominal load range of 75,000 lb/hr to 120,000 lb/hr. Measurements included continuous monitoring of O<sub>2</sub>, CO, CO<sub>2</sub>, NO<sub>x</sub>, and SO<sub>2</sub>, EPA Method 17 for particulate loading, and grab samples of fuel and ash streams.

Figure 6 shows the response of NO<sub>x</sub> emissions to cofire for low, intermediate and high boiler loads. Gas cofire in the range of 17 to 21 percent reduced NO<sub>x</sub> emissions by 17 to 19 percent. These reductions are sufficient to meet the plant goals for NO<sub>x</sub> trim. The data for these tests, shown in Table 1, show the excess oxygen levels were high, in the range of 9 to 12 percent. Spot tests, particularly at the low load condition, suggested that additional NO<sub>x</sub> reductions were achievable by reducing the high levels of excess air, although continuous operation at lower excess air would require a change in control system which was beyond the scope of the current modifications. Also, operation at low excess air levels would require more extensive testing to access effects on grate thermal response and long term ash properties.

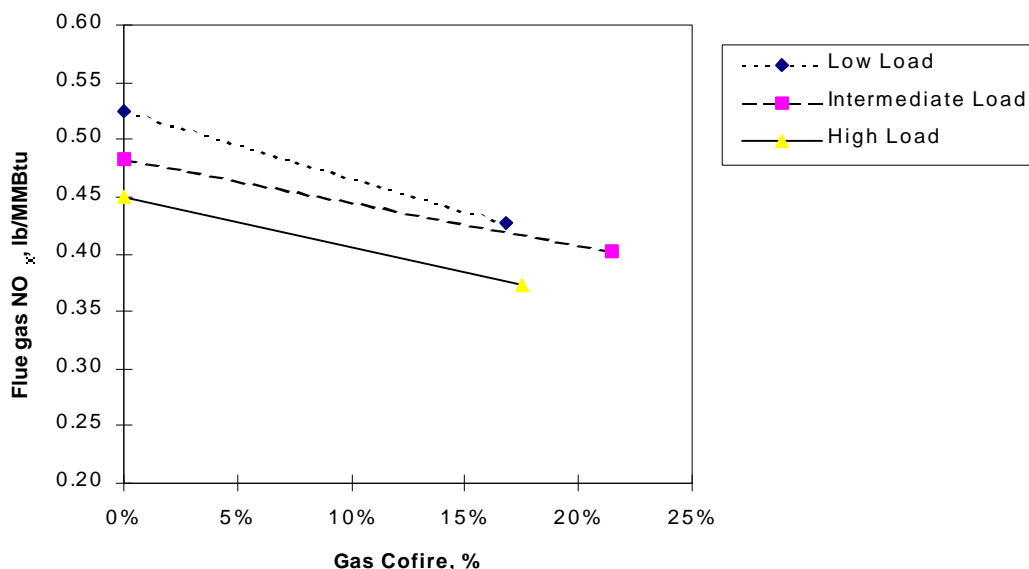


Figure 6. Capitol NO<sub>x</sub> Emission Results.



**Table 1. Capitol Emission Results.**

Boiler Load (kpph)	Gas Cofire (%)	O <sub>2</sub> (%)	CO <sub>2</sub> (%)	CO (ppm)	NO <sub>x</sub>	
					ppm	ppm @ 3% O <sub>2</sub>
76	0.0	12.2	6.9	26.0	176	362
70	16.8	11.9	7.3	7.0	162	322
99	0.0	11.1	8.7	13.0	195	356
100	21.5	10.7	8.4	5.0	174	305
122	0.0	10.4	9.2	15.0	194	331
120	17.5	9.1	9.5	12.2	186	282

### Washington Water Power

Wood-fired boilers can benefit from the same diverse range of performance and environmental benefits as coal-fired stokers. Almost always, however, the dominant benefit with wood-waste firing is overcoming the severe performance constraints caused by fuel variability, particularly fuel moisture. The reliability and efficiency of biomass for steam and power production can be severely limited by the variability of fuel quality. Excursions in fuel moisture content and composition can cause the boiler to be derated or cause the plant to be subject to environmental regulations. This is an increasing concern in the forest products industry as the average moisture content of wood waste is increasing as new growth trees occupy a larger part of the resource base and manufacturing improvements are utilizing the higher quality wood. Moisture levels in excess of 55 percent are common in winter months in many areas. These high moisture levels can cause the boiler flue gas throughput design capacities to be exceeded, thereby limiting steam generation capacity. Also, the high carbon monoxide levels and opacity resulting from the low temperature combustion zone with high moisture may require higher excess air levels to remain operational. These increased excess air levels further increase the flue gas throughput and aggravate the boiler derate.

Washington Water Power operates the 46 MW Kettle Falls Generating Station powered by a Combustion Engineering VU-40 biomass stoker with a continuous rating of 415,000 lb/hr. The plant fires hogged fuel processed on site. The nominal fuel design specification was for 40 to 50 percent moisture.

The power dispatch at the plant is seasonal and reflective of the competitive pricing of hydro power. During periods when hydro contributes a smaller amount of demand, the plant can profitably sell as much power as it can generate. The generating capacity at Kettle Falls, however, is currently limited below the peak sustained generating level of 46 MW. Due to high moisture content in the wood, the plant typically reaches peak generating capability at about 40 MW. This 10 percent shortfall in generating capacity is primarily due to limitations on the induced draft fan which peaks out due to the high flue gas throughput at high moisture levels.

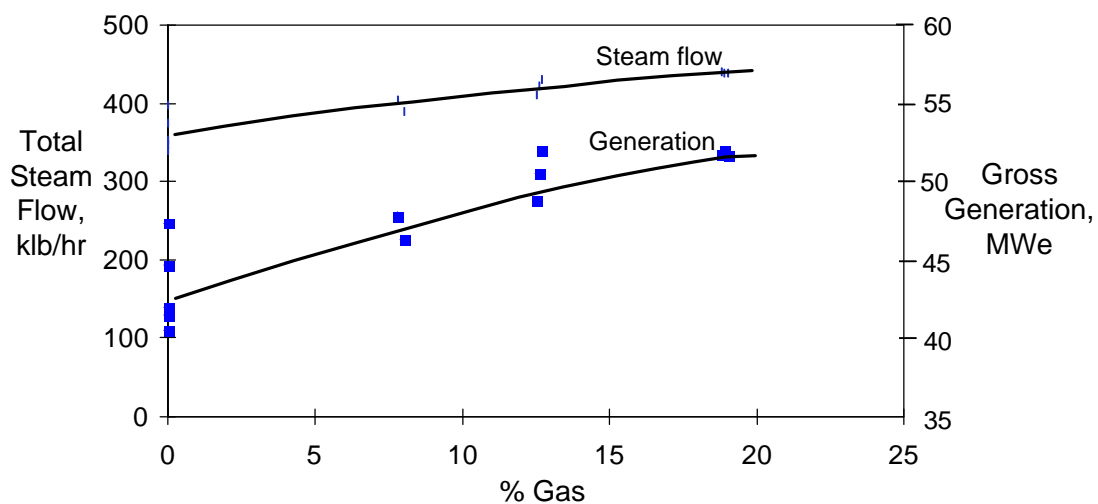
Although hogged fuel is the base fuel at the plant, the boiler was installed with CE gas nozzles and air registers positioned in each corner in a tangentially firing configuration. These burners have not been routinely used by the plant, but gas cofire is now being evaluated by the plant as part of the generating pattern during periods of high moisture fuel. The primary incentive for cofire is recovery of lost derate. Even though the cost of wood waste fuel is low at the plant, the incremental revenue from increased generation more than covers the incremental gas cost. Other benefits include:

- Increased efficiency due to displaced moisture, reduced excess air, and improved carbon burnout
- Elimination of short term load excursions caused by changes in fuel heating value and by transient burnthrough of wet wood piling on the grate
- Reduction of carbon monoxide emissions during periods of high moisture fuel
- Emergency standby for wood fuel feed failure or grate maintenance.

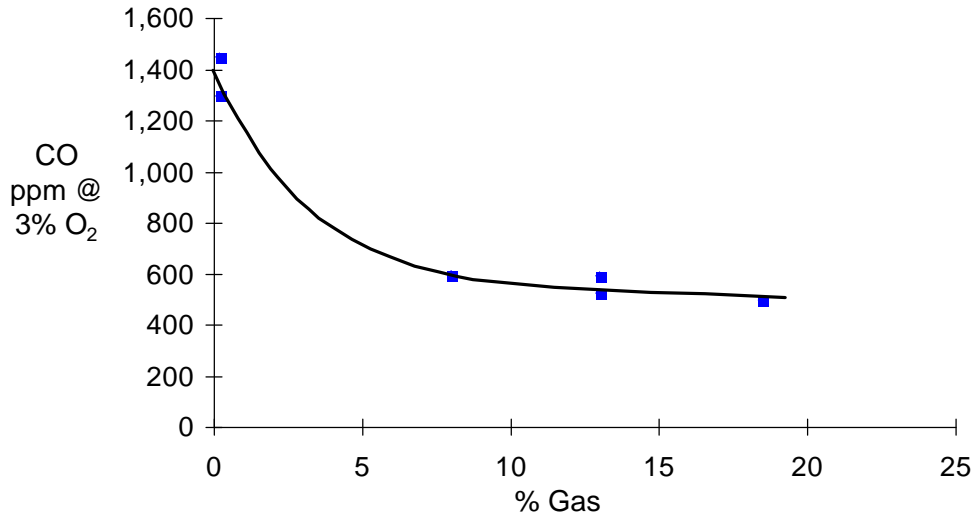
A test program was conducted in October and November, 1997 for cofire levels ranging from 0 to 25 percent, and various gas nozzle tilts and excess air levels. The tests were run at near full load, since this is where the derate condition exists.

Figure 7 shows the recovery in derate for total steam flow and plant generation. Gas cofire levels in the range of 15 to 20 percent were sufficient to recover up to 20 percent derate caused by the wet wood. The derate recovery is due both to displacing the moisture in the wood fuel with lower moisture in the natural gas, and to reduced combustion air made possible by the improved combustion conditions with the gas flame. The improvement in combustion conditions with a modest amount of gas is illustrated by the response of carbon monoxide to cofire shown in Figure 8. Cofiring of less than 10 percent gas gave higher temperatures above the grate, confirmed by in-furnace probing, and 50 percent or more CO reduction. The reduction in fuel moisture, coupled with reduced excess air, and higher steaming temperatures also gave a major improvement in plant heat rate. The fuel moisture for some of the runs was above 55 percent, which seriously degrades efficiency because much of the heat of combustion is used to counter the latent heat of vaporization in the wood. Figure 9 shows the overall plant heat rate response to cofire. The variability is due to short and long term excursions in fuel quality and other plant operational changes.

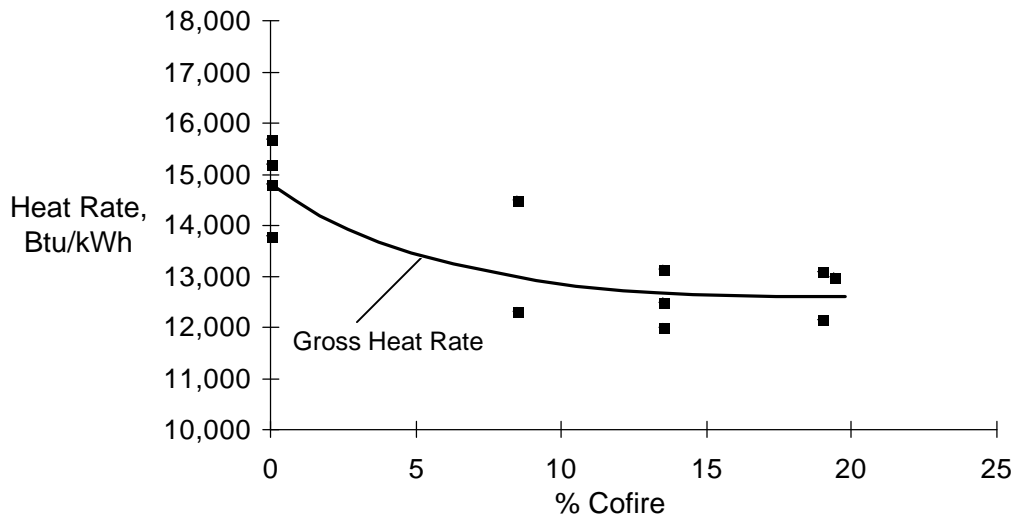
Particulate emissions were reduced approximately proportional to the displacement of wood by gas as shown in Figure 10. NO<sub>x</sub> emissions showed a slight decline as shown in Figure 11. This low response to cofire is due to the low temperatures with the wet wood which give low baseline emissions. Also, the high CO present at 100 percent wood firing acts as a reducing agent for NO<sub>x</sub>. Typically, for the dryer wood, baseline emissions increase and gas cofire produces a significant reduction in emissions.



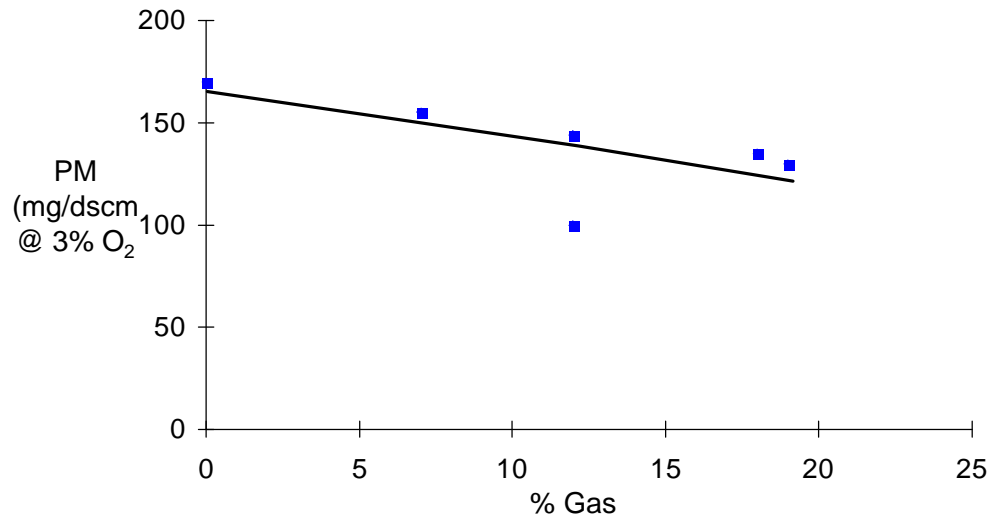
**Figure 7. Derate Recovery.**



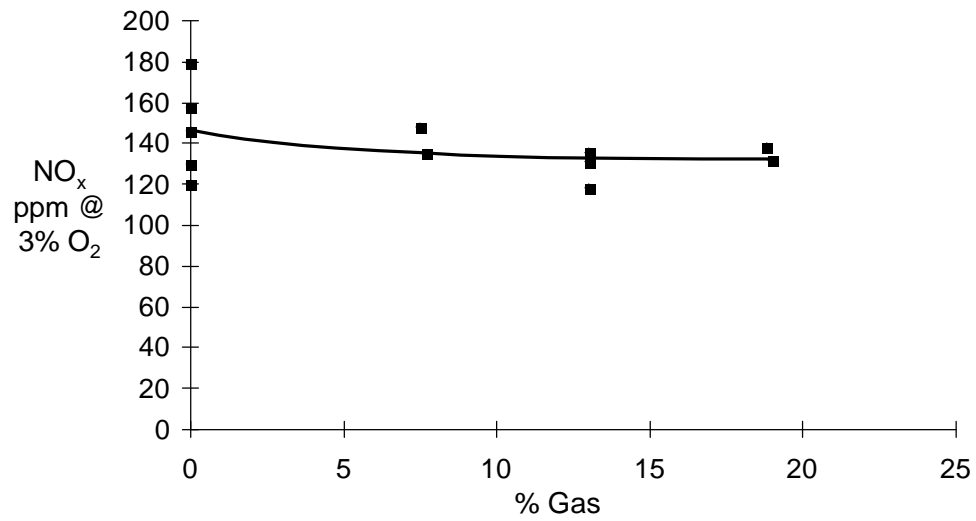
**Figure 8. WWP Carbon Monoxide Emissions.**



**Figure 9. WWP Plant Heat Rate.**



**Figure 10. WWP Total Particulate Emissions.**



**Figure 11. WWP NO<sub>x</sub> Emissions.**

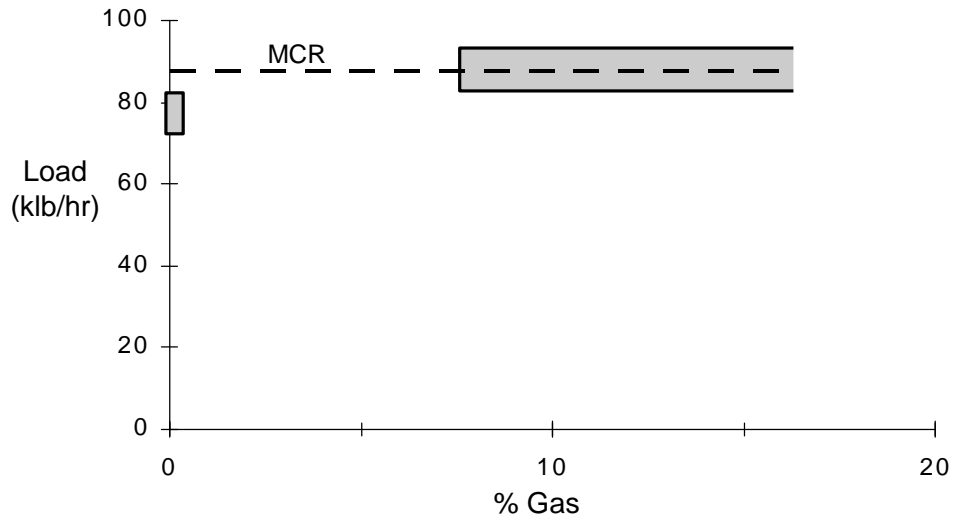
## Boise Cascade

Boise Cascade operates two 90,000 lb/hr Zurn boilers fired with wood waste fuel at the Emmett Cogeneration Plant. The boilers supply high pressure steam to a 15 Mw generator and low pressure process steam to kiln dryers. The plant initially used wood waste generated on site. Increasingly the plant is using hog fuel purchased outside with resultant lower quality and higher moisture variability. During winter months, it is now common for the plant to experience moisture contents in as-fired wood of 55 percent. These high moisture levels have several negative impacts:

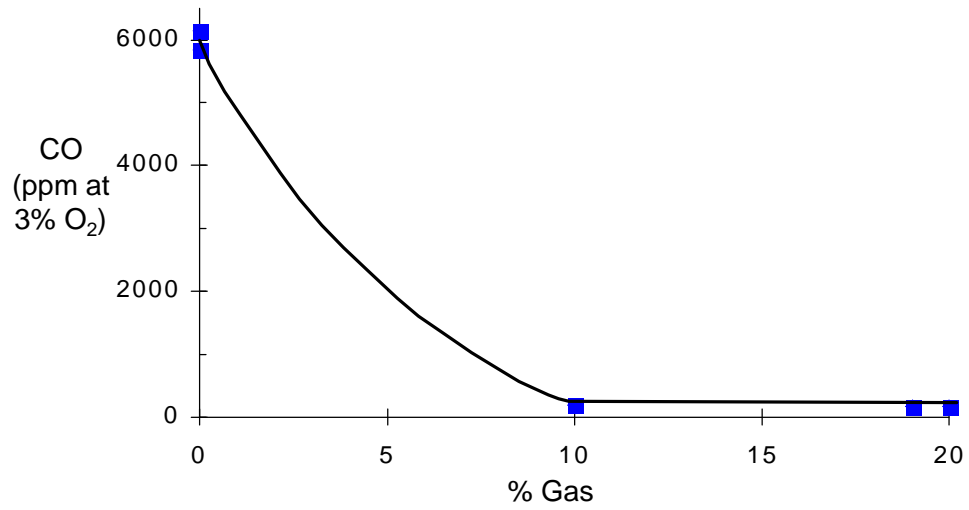
- Reduced boiler efficiency requiring more fuel to generate the required steam
- Increased emissions of carbon monoxide promoted by the lowered temperature and delayed combustion with the wet wood
- Increased levels of excess air to establish a satisfactory flame with the wet fuel
- Increased total combustion gas throughput because of the increased moisture and increased excess air.
- Capacity peaking of the induced draft fan at less than peak boiler load because of the high gas throughput
- Derating of the boiler because of ID fan limitations

The boiler derate causes lost revenue during periods when the plant can sell peak generating output through the PURPA contract.

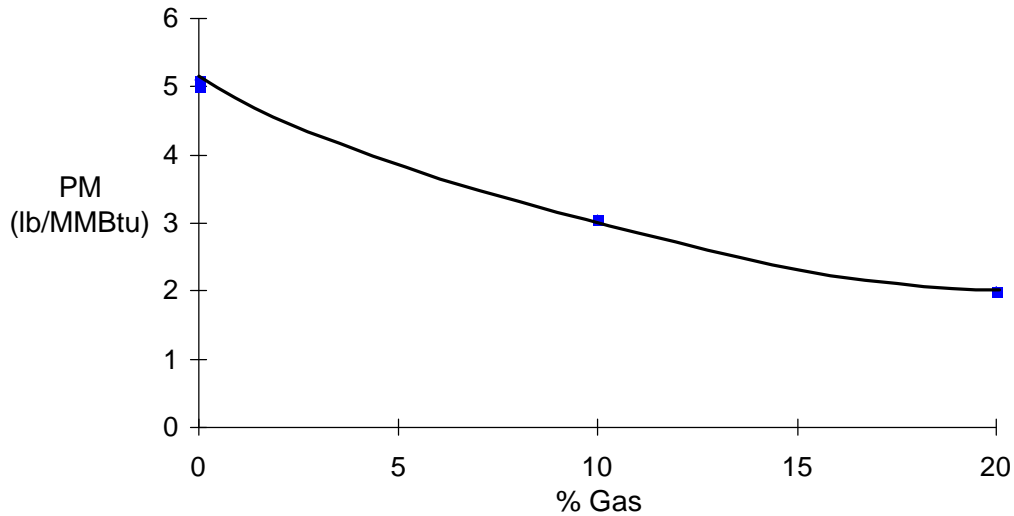
To counter the problems with wet wood, the plant installed dual Coen CoFyr burners with a total combined capacity of 60 MMBtu/hr in November 1997. The plant was tested periodically from December 1997 to June 1998 to evaluate cofire effects on boiler performance. The boiler capacity tests, summarized in Figure 12, showed that peak boiler load with wet wood was limited to 70,000 to 80,000 lb/hr, depending on the specific fuel characteristics. With a modest amount of cofire, typically less than 10 percent, loads in excess of maximum continuous rating (90,000 lb/hr) were achievable. Furnace probing above the grate showed that combustion gas temperatures with 100 percent wet wood firing were low, in the range of 1650 to 1750 F. Addition of 10 percent gas cofire raised the temperature by 100 to 150 F which greatly improved combustion conditions. This effect was clearly visible with in-furnace videos focused on the flame zone. The response of carbon monoxide emissions to cofire levels, shown in Figure 13, shows the improvement in combustion conditions with modest levels of cofire. Particulate emissions, shown in Figure 14 for measurements at the preheater exit, were also significantly improved with cofire. Cofiring 20 percent gas gave particulate reductions of up to 50 percent.



**Figure 12. Boise Cascade Derate Recovery.**



**Figure 13. Boise Cascade Carbon Monoxide Emissions.**



**Figure 14. Boise Cascade Particulate Emissions.**

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## ACKNOWLEDGEMENTS

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