CALIFORNIA
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COMMISSION

XONON® LOW-NOx CATALYTIC COMBUSTION IN PRACTICE:

CASE STUDY OF A 1,400 KW COMBUSTION TURBINE

PIER COLLABORATIVE REPORT

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Xonon® Low-NOx Catalytic Combustion in Practice

Case Study of a 1,400 kW Combustion Turbine

1013143

Final Report, April 2006

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PRODUCT DESCRIPTION

This case study documents the project development, implementation, and operational experience of a 1,400 kW Kawasaki combustion turbine operated by the Sonoma Developmental Center (SDC) in Eldridge, California. Over time, the system has been equipped with three NOx control technologies: water injection, dry-low NOx combustors, and Xonon Cool Combustion® catalytic combustion technology developed by Catalytica Energy Systems, which employs catalytic surfaces to burn the fuel (without flame) at temperatures below those at which NOx forms.

Results & Findings

This case study provides real-world data on performance of the Xonon® low-emissions combustion technology including emissions history over 12 years and including 27 months of Xonon®-equipped operation. The technology should be able to reduce combustion turbine NOx emissions below those permitted for large, central station power plants in California. The emissions data reported to date indicates that this objective has been largely met over the first 27 months of operation.

Challenges & Objectives

This report should be of use to utility generation planners who must plan for capacity with very low-NOx emissions. The technology implemented in this case study is capable of meeting the permitted emissions for large central station power plants in California. The report should also be of interest to utility personnel who are responsible for reducing emissions in existing generators as it can be retrofitted to many combustion turbines.

Applications, Values & Use

The success of the Xonon® technology in reducing NOx emissions at the site for which this case study was prepared suggests that the technology should be considered for other combustion turbine power plants. A logical next step would be to implement in at a larger, more commonly used combustion turbine model.

EPRI Perspective

The Sonoma Development Center Xonon® project has been reported in the popular literature for the last two years. This report is the first to report quantitative performance data including data from which O&M costs might be anticipated. It also serves to quantify the field performance of this very promising low-NOx technology.

Approach

The report was prepared from interviews with energy management and boiler plant personnel at the Sonoma Development Center as well as collation of operating logs over the 12 years of plant operation including 27 months of Xonon®-equipped combustor operation.

Keywords

Combustion turbine
Kawasaki
Catalytica Energy Systems
Xonon Cool Combustion®
Sonoma Developmental Center
Distributed generation
Distributed energy resources

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1
INTRODUCTION

This case study documents the project development, implementation, and operational experience of a 1,400-kW Kawasaki combustion turbine equipped, at different times, with three NOx control technologies: water injection, dry-low NOx combustion, and Xonon Cool Combustion® catalytic combustion technology developed by Catalytica Energy Systems. This report extends a previous EPRI report[1] to include an additional 11 months of operation.

After this Introduction, Section 2 provides background information about the project. Section 3 describes the Xonon® technology. Section 4 describes the system deployed at the Sonoma Developmental Center in Eldridge, California. Section 5 summarizes the system's operating history. Section 6 provides conclusions.

Sonoma Developmental Center

The Sonoma Developmental Center (SDC) in Eldridge, California, is a state residential facility that houses, educates, and treats individuals with developmental disabilities (Figure 1-1). Founded in 1891, SDC is administered by the California Department of Developmental Services. It currently houses approximately 850 residents on a campus that hosts a number of buildings spread over about 400 hectares. Center staff numbers about 2,200.

Approximately half of the SDC's main grounds are shown in Figure 1-2. A star indicates the location of the Kawasaki combustion turbine at the facility's central boiler plant. The map shows the plant's proximity to nearby laundry and kitchen facilities; the primary steam and hot water loads at the site. Steam is also generated at the central boiler plant to provide space heating for the entire campus, while two 1,250 RT electric-driven chillers located on the west end of the boiler house provide air conditioning for approximately half the facility's buildings.

[1] *Xonon® Low-NOx Catalytic Combustion in Practice: Case Study of a 1,400 kW Kawasaki Combustion Turbine at the Sonoma Development Center*. EPRI, Palo Alto, CA: 2004. 1008431.

Figure 1-1
Main entrance to the Sonoma Developmental Center

Figure 1-2
Map of SDC (star indicates CT location)

Kawasaki Gas Turbines

Kawasaki (www.kawasaki.com/gtd/index.html) has a long history in the gas turbine market. The company has been a major service provider for the aerospace turbine market for many years, with partners including GE, Pratt and Whitney, and Rolls Royce. Although Kawasaki's earliest efforts in the industrial gas turbine market focused on Japan and Southeast Asia, the company has had a presence in the Western Hemisphere since 1979, generally selling packaged systems through third parties. In recent years, Kawasaki Gas Turbines has been marketing, selling, packaging and servicing industrial gas turbine gensets in the Americas under the Kawasaki brand name, and currently estimates that it holds approximately 58% of the worldwide market share for turbines used for power generation in the 1- to 10-MW range. Figure 1-3 illustrates a typical Kawasaki genset package.

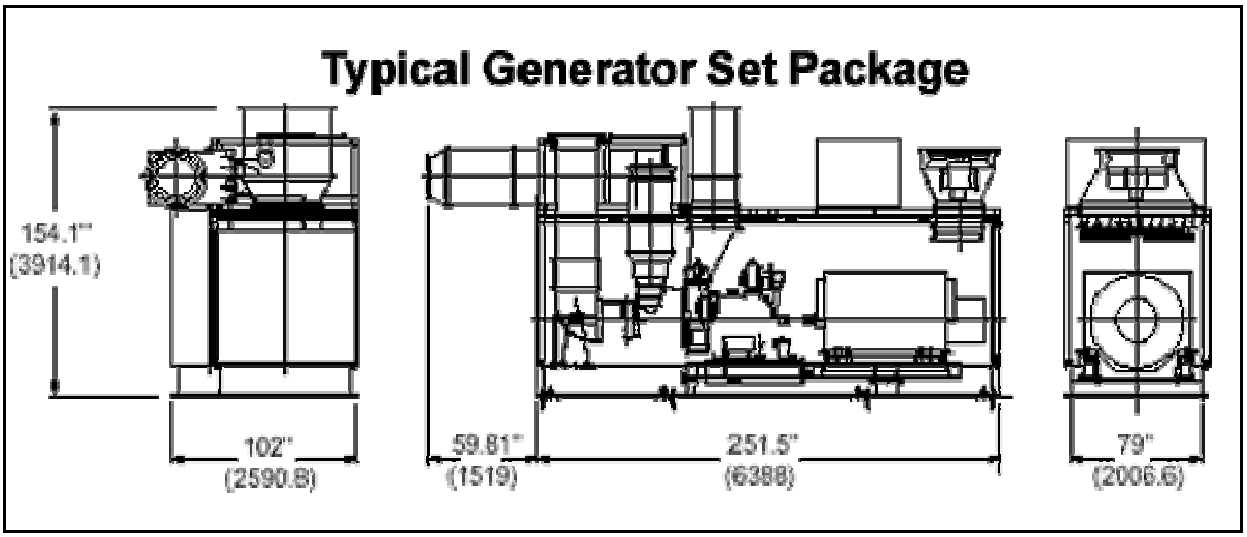

Figure 1-3
Typical Configuration of Kawasaki Low-NOx CT Package

Catalytica Energy Systems, Inc. (Catalytica)

Catalytica Energy Systems (http://www.catalyticaenergy.com/home.html) provides innovative emissions solutions to ease the environmental impact of combustion-related applications in the power generation and transportation industries. The Company has offices in Gilbert, Arizona, Mountain View, California and Charlotte, North Carolina.

Catalytica Energy Systems' business activities include the design, development and manufacture of advanced products based on its proprietary catalyst and fuel processing technologies to offer cost-effective solutions for reducing NOx emissions from natural gas-fired turbines and diesel engines. The Company's Xonon Cool Combustion® system offers a breakthrough pollution prevention approach for gas turbines to achieve ultra-low emissions power generation through a proprietary catalytic combustion process. Catalytica Energy Systems' diesel fuel processing technology is designed to enable significant NOx reduction from mobile, stationary and off-road diesel engines to meet the growing diesel emissions challenge. Other activities include the

development of fuel processing systems for fuel cell applications in stationary, auxiliary and back-up power.

Catalytica Energy Systems also offers, through its SCR-Tech subsidiary (www.scr-tech.com), a variety of services for coal-fired power plants and other utility-scale power generation facilities that use selective catalytic reduction (SCR) systems to reduce nitrogen oxides (NOx) emissions. These services include SCR catalyst cleaning and regeneration, as well as SCR system management and consulting services to optimize efficiency and reduce overall operating and maintenance costs.

2
PROJECT BACKGROUND

Original Genset Installation

In the mid-1980s, the Sonoma Developmental Center (SDC) conducted feasibility studies to determine if distributed generation coupled with cogeneration could help the center meet its electric and heating loads. In addition to high electric demand—some of which is due to the facility's hospital and health care facilities—SDC has a significant base load steam demand. The entire center is heated by a 3-mile (4.8-km) steam loop that, in addition to providing heat for space conditioning, also heats service hot water used in the facility's institutional kitchen and laundry. The base load demand for steam was a primary driver of SDC's interest in the combined heat and power project.

In 1986, the SDC applied for and received funding to install a 1,400 kW Kawasaki M1A-13D gas turbine equipped with a water injection for NOx emissions control. The genset was equipped with a heat recovery steam generator and was capable of firing either natural gas or fuel oil. The HRSG also included duct burners capable of firing natural gas or fuel oil. The $3.9 million project was funded by a revenue bond issued through the California Office of Energy Assessments. SDC repaid the bond in 11 years with energy savings realized by operating the system.

The project was sized to meet SDC's baseload electrical and steam demands. At night, the genset provides essentially all of the center's electricity. During the day, when electrical demand is greater, the turbine's output is supplemented by electricity from PG&E, the local electrical utility. Heat and electrical demand vary seasonally. On average, SDC purchases 23% of its electricity from PG&E and generates the remainder on site. The system is dispatched to not export any electricity to the PG&E grid and is not currently capable of islanded, off-grid operation.

The original unit was installed and maintained (under contract) by U.S. Turbine, which was subsequently acquired by Rolls Royce. The original turbine experienced bearing problems and broke down twice, in 1996 and 1997. Rolls Royce replaced the turbine in 1998 under an existing service agreement. The replacement turbine was equipped with staged (dry, low NOx) combustors.

New Xonon®-Equipped Genset

In 2002, Kawasaki and Catalytica approached SDC about hosting one of the first commercial Xonon Cool Combustion® systems in the country. The companies sought a site in the United

States that had prior experience with Kawasaki turbines and could provide a good showcase for the Xonon® technology.

A significant incentive for SDC to pursue the project was a 20 parts per million (ppm) NOx emission limit imposed by California's Bay Area Air Quality Management District, under whose authority SDC operates the gas turbine. Emissions from the original plant often approached and occasionally exceeded that limit.

Furthermore, when SDC made it clear that the center had no funds available for the project, Kawasaki offered favorable terms that included paying for much of the installation themselves. Other funding for the project was provided by the California Energy Commission (CEC). Through an inter-agency agreement, the CEC contributed $105,000 to the project via its Public Interest Energy Research (PIER) program. (The California energy Commission's PIER program had invested more than $3 million in Catalytica over four years to support the development of Xonon® technology[2,3].)

Kawasaki had hoped to use SDC's original M1A-13D turbine for the project. However, given the turbine's age and service history, Kawasaki decided that it should be replaced. In Fall 2002, Kawasaki provided an advanced, zero-hour M1A-13X turbine and installed it at the SDC site. Since the fuel gas compressor serving the old genset would not carry sufficient pressure to support the new turbine, Kawasaki also leased the center a new compressor at a cost of $1 for three years. In addition, the enclosure housing the turbine had to be modified to accommodate the new combustor's greater height.

SDC reports that the six-week retrofit proceeded smoothly. One significant change was the installation of a new Woodward Atlas control system, which initially caused some interface problems unrelated to the new combustor. The reconfigured plant returned to operation in November 2002.

Contractual Arrangements

As part of the original installation, U.S. Power was also awarded a maintenance and service contract. This arrangement continued after U.S. Power was acquired by Rolls Royce in the mid-1990s and through Summer 2002, at which point Kawasaki was contracted to provide service and maintenance as part of the Xonon® retrofit.

All of SDC's contractual arrangements are with Kawasaki. Catalytica Energy Systems serves as a Kawasaki subcontractor. SDC's agreement with Kawasaki called for guaranteed 95% availability in the first year, 94% in the second, and 93% in the third. These targets allow for 36.5, 43.8, and 51.1 hours of monthly mechanical maintenance down time, respectively. In the

[2] Low NOX Gas Turbine Combustors for Distributed Power Generation. California Energy Commission PIER Program Final Report. P600-01-002. March 2000. (www.energy.ca.gov/reports/2002-01-11_600-01-002.PDF).

[3] Durability of Catalytic Combustion Systems. California Energy Commission PIER Program Final Report. P500-02-040F. March 2002. (www.energy.ca.gov/pier/final_project_reports/500-02-040f.html).

event of monthly maintenance outage hours exceeding these targets, Kawasaki agreed to pay SDC $.060 per kWh for lost generation during the excess hours.

The maintenance agreement with Kawasaki is priced at a cost of $27,000 per month (the center's previous maintenance contract with U.S. Power/Rolls Royce was $22,000 per month). The agreement also has a clause that requires Kawasaki to return the plant to its original, pre-retrofit configuration in the event of complete turbine or emission control system failure.

3
XONON® TECHNOLOGY AND APPLICATIONS

Technology Description

Combustion turbines typically operate with very high overall air/fuel ratios that are above the lean limit for sustained combustion. To maintain stable flames, the fuel is combined with a fraction of the total air in a mixture that is within flammability limits. Flame combustion products are cooled with the excess air before entering the turbine nozzles. Oxides of nitrogen are formed in the high-temperature flame. To the extent that flame temperatures can be reduced by injecting water or by staging the combustion (with smaller amounts of fuel in a high-temperature flame and the remaining fuel in a lower temperature flame) production of NOx can be limited.

The Xonon Cool Combustion® system uses a catalyst instead of a flame in the combustion process. This allows complete mixing of the fuel and total air with the combustion initiated by a catalytic surface and occurring at temperatures below those at which measurable amounts of NOx form. The Xonon® unit is contained within the gas turbine's combustion chamber as shown in Figure 3-1. The fuel-air mixture reacts to produce a high-temperature mixture, typically about 1,300°C (2,300°F). Dilution air is added to shape the temperature profile required at the turbine inlet.

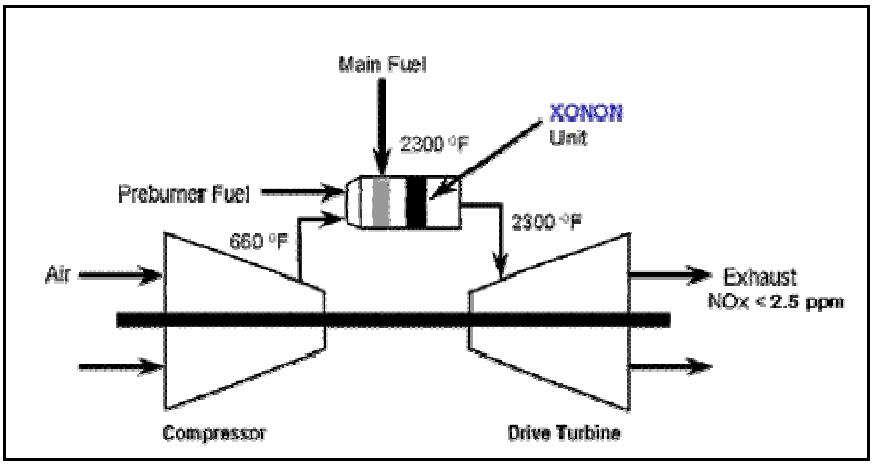

Figure 3-1
Xonon Cool Combustion® System

The Xonon® system consists of four sections as shown in Figure 3-2:

- **Preburner.** The preburner uses a small fraction of the fuel to heat the larger air/fuel mixture (before it enters the catalyst module) to the catalyst light-off temperature. The burner is also used during startup for acceleration of the turbine.
- **Fuel injection and fuel/air mixing system.** This unit meters the fuel and mixes it with the main air flow to provide a well-mixed, uniform fuel/air mixture to the catalyst.
- **Xonon® catalyst module.** In the catalyst module, the pre-warmed fuel/air mixture passes through the catalyst in which approximately half of the fuel combines with air at the catalyst surface without a flame to produce a higher-temperature mixture of combustion products and unreacted fuel/air.
- **Homogeneous burnout zone.** Located immediately downstream of the catalyst module, the homogeneous burnout zone is where the gas temperature is high enough such that the remainder of the fuel is burned (without the need of a catalyst) at temperatures below those at which NOx forms. Carbon monoxide and unburned hydrocarbons are also reduced to very low levels.

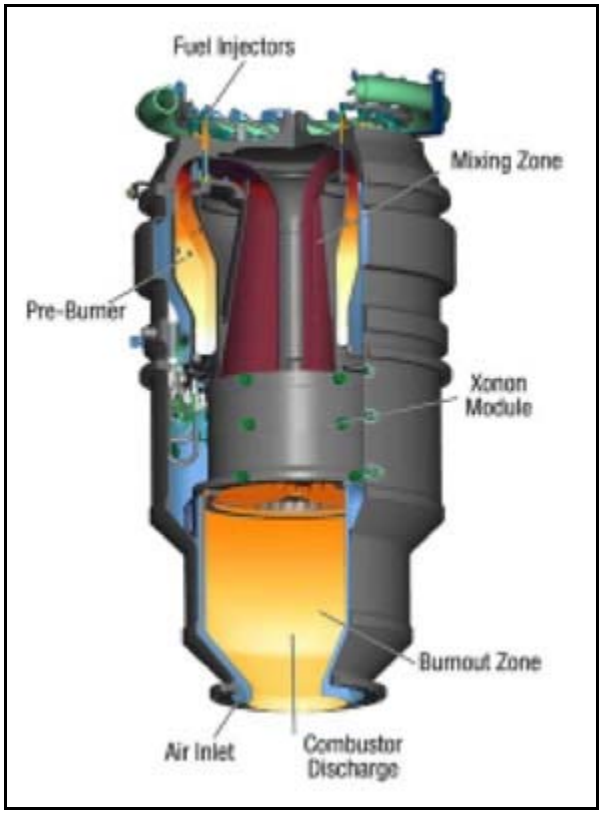

Figure 3-2
Xonon® Combustor

The overall combustion process consists of a partial combustion of fuel in the catalyst module followed by complete combustion downstream in the burnout zone. Partial combustion within the catalyst produces no NOx. Homogeneous combustion downstream of the catalyst usually produces no NOx because combustion occurs at a uniformly low temperature. A small amount of fuel is burned in a high temperature flame in the preburner to raise the compressed air temperature to approximately 470°C (880°F) before entering the catalyst module. Any NOx in the turbine exhaust usually results from this preburner combustion. Kawasaki reports that the GPB15X (the current commercial version of the Xonon® technology) demonstrates comparable levels of ultra-low emissions at both baseload and partial-load conditions down to 70% of the rated turbine output.

Development of the Xonon® technology was described in a previous EPRISolutions report[4].

Training and Support

Training needed to operate and service the equipment is provided by Kawasaki personnel during initial startup and shakedown. Maintenance procedures and spare parts requirements are provided upon delivery of the equipment.

After initial commissioning, a Xonon® system is expected to require minimal ongoing service. The catalyst module will have a useful life of approximately 8,000 operating hours, after which it will need to be replaced.

In December 2002, Kawasaki signed a distribution agreement with Cummins Power Generation for Cummins to market, sell and service gensets powered by Kawasaki gas turbines in the Americas. Cummins is experienced with the design and manufacture of diesel and gas generator sets from 5 kW to 2,700 kW used for standby, peaking, and prime-rated power systems. The agreement spells out a multi-year alliance that involves Cummins marketing Kawasaki gensets ranging from 1,400 to 7,000 kW in size under a co-branded designation. The two also agreed to share in certain marketing efforts related to materials and market development activities, and may eventually expand geographical distribution.

Cummins is not involved with the Sonoma Developmental Center project. All current SDC contracts are between SDC and Kawasaki.

Other Xonon® Installations

Though the SDC installation represents the first commercial Xonon® project, the technology has been installed or is under construction at other sites in the United States.

[4] *Development and Validation of Catalytic Combustion for Gas Turbines, Final Report.* EPRIsolutions, Palo Alto, CA and Gas Technology Institute, Chicago, IL. TR-113895. 2000.

Silicon Valley Power

Silicon Valley Power (SVP) in Santa Clara, California, hosted the first development and demonstration site for the Xonon® technology. It was incorporated into the combustor of a 1,400 kW Kawasaki M1A-13A gas turbine and began operating in 1999. The permit limit at the site was 5 ppmvd NOx at 15% O_2. From installation until the end of operations in June 2004, the turbine served as a demonstration of Xonon's performance and as a development and test unit to support Catalytica's commercial initiatives. The system accumulated more than 20,000 hours of reliable operation at this site with NOx emissions consistently below 3 ppmvd.

Plains Exploration & Production Co.

A Xonon® system installed at an oil field owned by the Plains Exploration & Production Co. (PXP) is the first complete, new commercial plant installed by Kawasaki. (The Sonoma Developmental Center plant is considered a retrofit.) The PXP system consists of a Kawasaki GPB15X gas turbine and cogeneration plant that has operated at its site near San Luis Obispo, California, since November 2003. Permitted emission limits are 3.0 ppmvd NOx, 10.0 ppmvd CO, and 2.0 ppmvd volatile organic compounds (VOC) over a three-hour rolling average. Kawasaki reports that the unit has achieved continuous NOx emission levels as low as 0.8 ppmvd at 15% O_2, with other emissions correspondingly low.

Other Projects

In addition, Kawasaki has announced plans to install a Xonon-equipped combustion turbine at the Reader's Digest Association headquarters building in Pleasantville, N.Y., where the genset will provide 75% of the facility's power. The unit is being installed by Carrier Corp. as part of an integrated heating and cooling package for the 650,000-square-foot facility.

Construction is also underway at a new commercial site in California, where a Kawasaki GPB15X cogeneration system with Xonon® technology will be installed at Pacific Union College in the Napa Valley to provide supplemental heat and power for a 200-acre campus.

EPA and CARB Assessments

Performance claims for the Xonon® combustion system have been verified by testing conducted by the U.S. EPA's Environmental Technology Verification (ETV) Program[5]. The EPA reviewed the results of tests conducted at Silicon Valley Power's Santa Clara facility in July 2000 and reported the results summarized in Table 3-1.

[5] Environmental Technology Verification Report, NOx Control Technologies: Catalytica Combustion Systems, Inc. Xonon Flameless Combustion System. U.S. Environmental Protection Agency. December 2000. www.epa.gov/etv/pdfs/vrvs/05_vr_xonon.pdf.

Table 3-1
U.S. EPA ETV Verification Statement of Xonon® NOx Control Performance

Ambient Temperature	Percent of Full Turbine Load Range	Mean Outlet NOx Concentration (ppmvd @ 15% O_2)	Half-Width of 95% Confidence Interval on Mean Outlet NOx (ppmvd @ 15% O_2)
59-77°F (15-25°C)	98%-99%	1.13	0.026

During the same tests, carbon monoxide (CO) emissions averaged 1.36 ppmvd and unburned hydrocarbons (UHC) averaged 0.16 ppmvd.

The California Air Resources Board (CARB) also evaluated the Xonon® performance claims through its Equipment and Process Pre-certification Program[6]. CARB staff reviewed NOx and carbon monoxide (CO) data collected from the Silicon Valley Power plant in 1999, including startup and shutdown periods. CARB verified Catalytica claims that Xonon® achieved a NOx level less than 2.5 ppmvd at 15% O_2, and a CO level less than 6.0 ppmvd at 15% O_2, over a one-hour rolling average when running at an operating load 98% or greater of design capacity.

CARB has published guidelines for permitting on-site generators in California[7]. Table 3-2 shows the January 1, 2007 emissions standards that generators must meet, along with the Silicon Valley Power site data collected for the U.S. EPA in 2000. These data show that the Xonon®-equipped Kawasaki combustion turbine should be able to comply with the CARB 2007 emissions guidelines in electric only applications. (The CARB guidelines are more relaxed for combined-heat-and-power applications.)

Table 3-2
CARB 2007 Emission Standards and Xonon® Performance
(ppmv converted to lb/MWh using CARB procedures)

Pollutant	CARB 2007 Emission Standard	Kawasaki M1A-13A with Xonon® reported by U.S. EPA @ 22.8% efficiency	
	lb/MWh	ppmv @ 15% O2	lb/MWh
Oxides of Nitrogen (NOx)	0.07	1.13	0.063
Carbon Monoxide (CO)	0.10	1.36	0.027
Volatile Organic Compounds (VOCs)	0.02	0.16	0.006

[6] Evaluation of the Air Quality Performance Claims for the Catalytica Energy Systems, Inc. Xonon Cool Combustion Technology. California Environmental Protection Agency Air Resources Board. June 2002. (www.arb.ca.gov/eqpr/catalyticareport.pdf)

[7] Guidance for the Permitting of Electrical Generation Technologies. California Environmental Protection Agency Air Resources Board. July 2002. www.arb.ca.gov/energy/dg/dg.htm.

4
SONOMA DEVELOPMENT CENTER PROJECT DESCRIPTION

Sonoma Developmental Center Boiler Plant

The boiler plant at the Sonoma Developmental Center consists of three direct-fired steam generators and the combustion turbine heat recovery steam generator (HRSG). All boilers operate at a nominal 100 psig, saturated, and are capable of being fired with natural gas or fuel oil. The steam generators are rated as follows:

- Boiler #1 30,000 lb/hr
- HRSG/Boiler #2 7,000 lb/hr unfired, 25,000 lb/hr fired (duct burners)
- Boiler #3 40,000 lb/hr
- Boiler #4 50,000 lb/hr

The minimum steam load at the site is approximately 7,000 lb/hr. The unfired HRSG is capable of supplying this minimum steam load. Peak site steam load is approximately 40,000 lb/hr.

Combustion Turbine-Generator/Heat Recovery Steam Generator

The combustion turbine installed at the site is a Kawasaki M1A-13X rated at 1,400 kW, 2,400 VAC. Nominal performance of the GPB15X, Kawasaki's current commercial offering incorporating the Xonon® technology, is shown in Table 4-1.

Table 4-1
Kawasaki GPB15X (successor to the M1A-13X) Nominal Performance

Ambient Temp.	Electrical Output	Fuel Use	Electrical Efficiency	Natural Gas Flow	Inlet Air Flow	Exhaust Flow	Exhaust Temperature
°F	kWe	MMBtuh (LHV)	% LHV	SCF/hr	lb/sec	lb/sec	°F
32	1,621	22.8	24.2	25,207	18.60	18.99	981
59	1,423	20.7	23.4	22,888	17.23	17.58	995
86	1,212	18.8	22.0	20,746	15.91	16.22	1018
104	1,072	17.6	20.8	19,395	15.05	15.34	1036

The turbogenerator is mounted in an enclosure that sits outside the north side of the boiler house as shown in Figure 4-1.

The turbine exhaust flows through the HRSG inside the boiler house. Duct burners are installed between the turbine exhaust and HRSG. Natural gas or fuel oil may be fired in the duct burners. A damper is installed to bypass turbine exhaust around the HRSG during start-up and to modulate steam flow when steam demand is less than the unfired rating of 7,000 lb/hr. The bypass damper is normally positioned for 100% turbine exhaust flow to the HRSG.

A continuous emissions monitor is installed in the exhaust of the HRSG. This monitor measures NOx emissions of the combustion turbine and duct burners combined.

Figure 4-1
Kawasaki M1A-13X Enclosure End/Inlet Air Filter and Side View

Fuel Gas Supply

Filtered natural gas is metered to the boiler plant at 130 to 250 psig. Gas is metered separately to the turbine and to the duct burners between the turbine and the HRSG.

The turbogenerator requires that fuel gas be compressed to in excess of 280 psig. An Ariel JGP-1 compressor was installed as part of the Xonon® retrofit in 2002. A picture of the gas handling skid is shown in Figure 4-2.

Figure 4-2
Fuel Gas Handling Skid

Combustion Turbine Auxiliaries

An auxiliary Motor Control Center (MCC), shown in Figure 4-3, feeds auxiliaries serving the combustion turbine. This MCC is separately metered to quantify auxiliary power use. This metered auxiliary power use is on average less than 6% of the gross generation. The auxiliaries powered by this MCC include:

- Generator enclosure ventilation fan
- Fuel gas compressor
- Fuel gas compressor gas cooler fan
- Control voltage transformer
- Bypass damper drive
- Lubricating oil cooler fan
- Starter battery charger.

Figure 4-3
Auxiliary Motor Control Center

4.5 Electrical Interconnection

The generator electrical output goes to a synchronizing breaker cabinet supplied by CGI Systems, Paramount, California. This cabinet houses the synchronizing breaker rated at 2400 VAC, 1200 amp. Protective relay functions 27 (undervoltage), 59 (overvoltage), and 81O/U (over/under frequency) are built into the cabinet.

A separate protective relaying cabinet was supplied by U.S. Power as part of the original installation. Basler discreet component relays are included for:

- 27/59N Under/Over voltage
- 87G Generator phase-phase winding protection
- 46 Current imbalance
- 32 Anti-motoring
- 40 Loss of field voltage or current supply
- 94G Transfer trip
- 50/51V Overcurrent with voltage restraint or voltage control, each phase

The relays operate the generator breaker in the synchronizing breaker cabinet.

4.6 Standby Generators On-site

There are six (6) diesel-fueled standby generators at the SDC. Three (3) of these units are smaller generators that power various emergency loads. Three (3) additional 850-kW diesel standby generators near the boiler plant that serve as 100% backup for the SDC. The smaller generators drop off line once the 100% backup generators are in service.

The combustion turbine-generator is not operated during utility outages, as there are no provisions for automatic voltage or frequency regulation installed.

4.7 Generator Dispatch

Since entering service in November 2002, the Sonoma Developmental Center combustion turbine equipped with Xonon® technology has operated in base load service. The generator is normally dispatched at full load but may be dispatched at part load if the site electrical load drops below 1,400 kW.

Steam generated by the HRSG is usually less than the site steam load. The duct burner is used to modulate steam output between 7,000 and 25,000 lb/hr. The HRSG bypass damper is used to modulate steam output between 0 and 7,000 lb/hr. The bypass damper is almost always open 100% to the HRSG.

5
SONOMA DEVELOPMENTAL CENTER COMBUSTION TURBINE OPERATING HISTORY

Electric Generation

The yearly electric generation over the life of the project is shown in Figure 5-1. Over the indicated 12 years, the average electrical capacity factor is 58%. Some of the lost capacity in 1996 and 1997 was due to mechanical failures in the turbogenerator, which were remedied by replacing it in 1998. Much of the remaining capacity loss is due to dispatch at less than 100% load due to low electrical or steam demand.

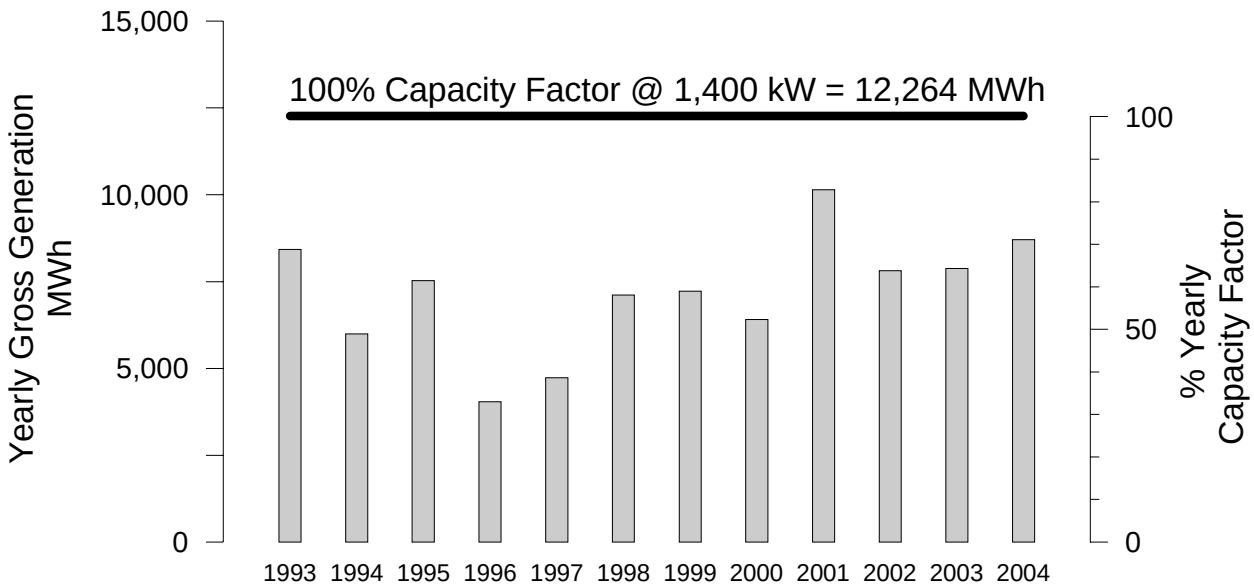

Figure 5-1
Yearly Gross Generation

O&M and Reliability

The Xonon®-equipped combustion turbine was placed in regular service beginning January 2003. The operating history of the unit during the ensuing 27 months is shown in Figure 5-2. Gas turbine maintenance hours are those for outages taken to do repairs, replacement, or routine maintenance on the gas turbine-generator and fuel gas compressor. SDC-requested hours are for outages taken to do scheduled testing or maintenance on items auxiliary to the gas turbine

including the heat recovery steam generator, controls, and switchgear. The overall on-line rate for the period shown is 75%. The gas turbine maintenance outage rate is 11%. Note that the logged mechanical outage hours are largely for components other than the Xonon® combustion system. The outage rate specifically for replacing the Xonon® combustion system is approximately 1%.

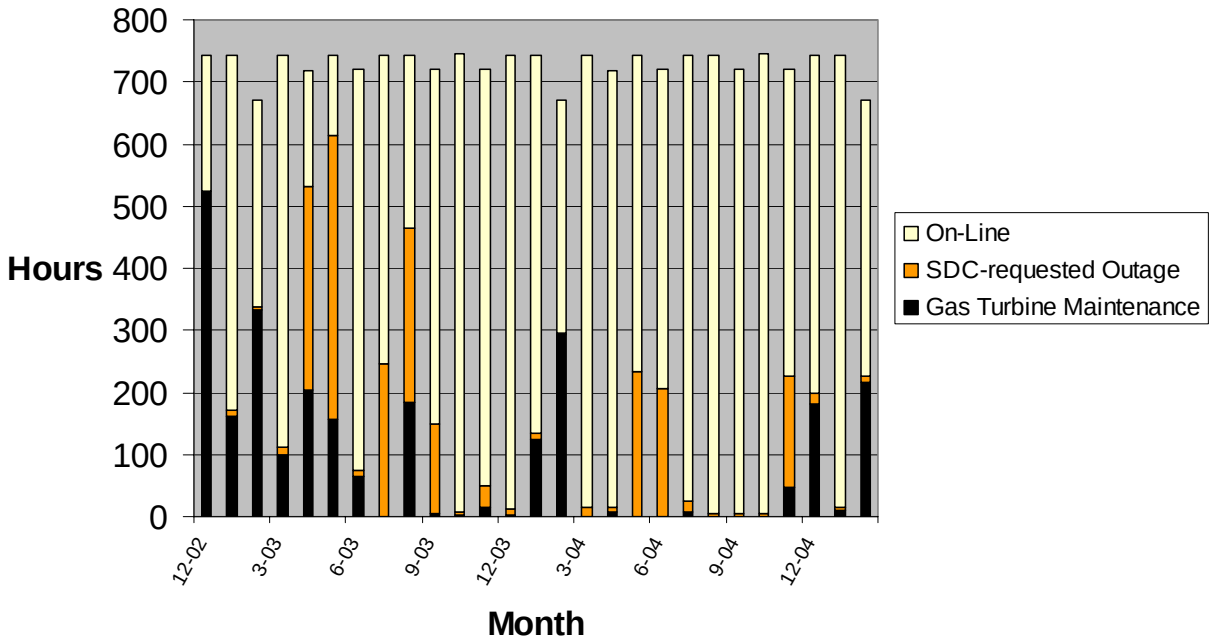

Figure 5-2
Outage/On-line hours logged with the Xonon® Combustor. SDC-requested outages are for maintenance and service on components other than the fuel gas compressor and combustion turbo-generator.

The following list summarizes the major gas-turbine-related outages:

December 2002	Residual start-up activities and maintenance
January 2003	Miscellaneous mechanical trips
February 2003	Gas compressor adjustments, generator bearing replacement
March 2003	Kawasaki-requested outage
April 2003	Kawasaki-requested outage
May 2003	Kawasaki-requested outage
June 2003	Miscellaneous mechanical trips
August 2003	Gas compressor repair
January 2004	Miscellaneous mechanical trips
February 2004	Kawasaki-requested outage, bearing troubleshooting/repair
May 2004	Electrical interconnection repairs/maintenance
June 2004	Annual HRSG maintenance and inspection
November 2004	Xonon® combustor catalyst replacement
December 2004	Gas compressor maintenance, generator repair
February 2005	Gas compressor repair, turbine high-temperature outages

Subsequent to the outages in February 2005 it was determined that the combustion turbine required major mechanical repair, unrelated to the Xonon® combustion system. This effectively resulted in the conclusion of the planned 3-year Xonon Cool Combustion® test period originally planned.

The Xonon® catalyst module was replaced in September 2003 after approximately 4,500 hours of fired service. The September 2003 replacement catalyst module logged 8,631 hours of operation. The November 2004 replacement catalyst module logged 2,183 hours through February 2005.

NOx Emissions

NOx emissions are recorded by a continuous emissions monitor located in the exhaust stack. This monitor makes a single measurement of NOx produced in both the combustion turbine and the HRSG duct burners. Rolling three-hour averages of NOx and O_2 concentrations are computed. The maximum value of the rolling three-hour averages for each 24-hour day is reported to the Bay Area Air Quality Management District (BAAQMD). These maximum three-hour averages are used to compute maximum daily NOx emissions in pounds, which are also reported to BAAQMD. The data reported below are derived from these reports of three-hour maximum emissions. Actual NOx emissions are equal to or less than the values reported.

Figure 5-3 shows the site NOx emissions rates over the history of the installation. The three combustor technologies employed are indicated in the figure. (Note that the changes in combustion technology were accomplished by complete combustion turbine replacements.) There was a modest reduction in NOx emissions when the staged combustion turbogenerator replaced the water injection turbogenerator. There was a significant reduction in NOx emissions when the Xonon®-equipped turbogenerator was installed. The median monthly NOx emissions factor for the Xonon®-equipped turbogenertor/HRSG duct burner through May 2004 was 0.2 lb/MWh with a maximum of 0.5 lb/MWh. (Data for May 2004 ff. is not available due to inaccuracies in fuel flow measurement to the gas turbine.)

The monthly data for the Xonon®-equipped turbogenerator are shown in Figure 5-4. The median of the daily three-hour maximum average NOx concentrations is plotted along with the minimum, maximum, and 10%ile and 90%ile. Most of the daily reports show NOx concentrations consistently below the permitted 20 ppmv (with three exceptions). Figure 5-5 shows the distribution of daily three-hour maximum average NOx concentrations over the 630 days during which Xonon®-equipped turbogenerator operation was logged.

The monthly median of the daily maximum 3-hour running average exhaust NOx concentration (reported by the continuous emissions monitor) was in the 3-5 ppm range through February 2004. This monthly median rose to 6-9 ppmv range for March 2004 and following months. The plant operators noted that during March-May 2004 the HRSG duct burner gas use was elevated which correlates with the rise in NOx emissions. However, the gas use returned to more normal levels in June 2004 and following months. They could not identify any other operational or maintenance reason for the continuation of the higher NOx emissions. It is, however, likely that the elevated NOx emissions are generated in the HRSG duct burners rather than the gas turbine

combustor. (Note that emissions following March 2004 are still largely below the 20 ppmv permit requirement for the site.)

During July 2003 the unit was operated for six days with the exhaust bypassing the HRSG. During this time, there was no NOx production in the HRSG duct burners and the data reported are for the combustion turbine only. The data for these days and the 15 days following are shown in Figure 5-6. The median daily maximum three-hour NOx concentration for operation bypassing the HRSG was 2.4 ppmv with a maximum of 3.0 ppmv. During the 15 days following, the median daily maximum three-hour NOx concentration was 3.8 ppmv with a maximum of 6 ppmv. Operation of the duct burners during this period increased NOx emissions by approximately 60% up to as much as 150%.

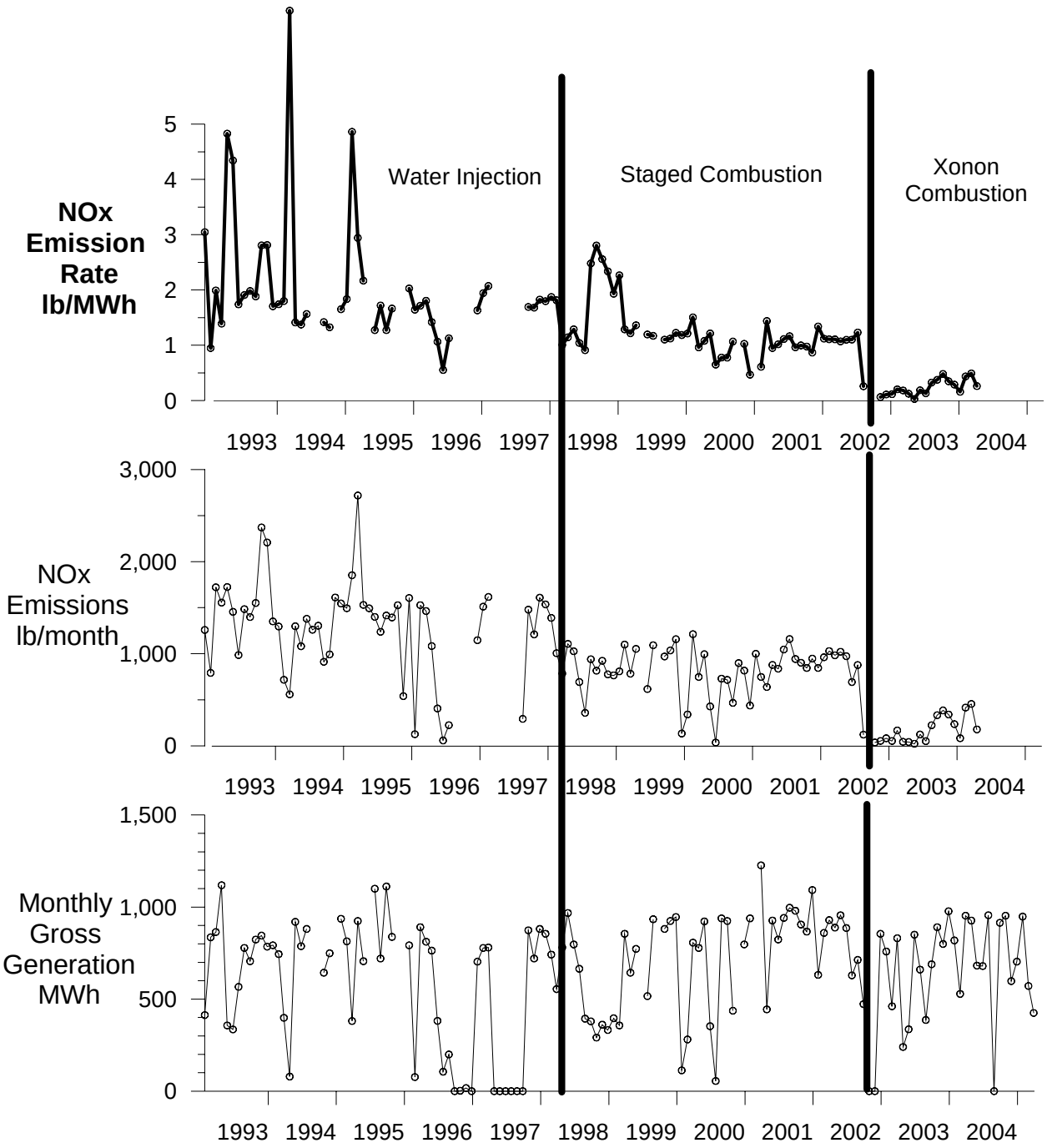

Figure 5-3
Monthly Average NOx Emission Rate Over the Project Life for Water Injection, Staged Combustion, and Xonon® Combustion. Data include combined NOx produced in both the combustion turbine and the HRSG duct burner. (NOx emission rates for May 2004 ff. are not available due to faulty combustion turbine gas meter readings.)

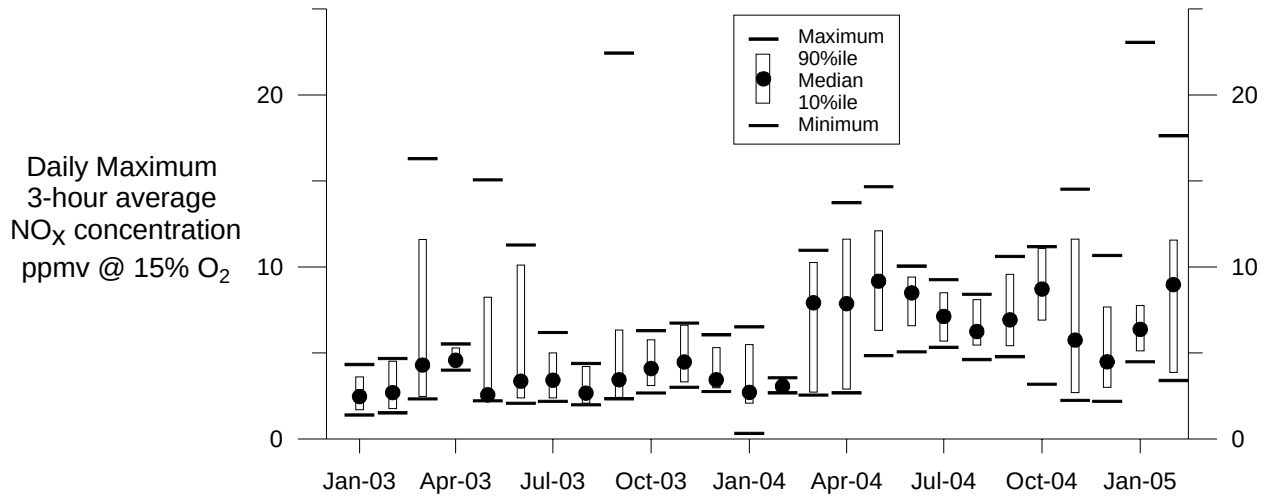

Figure 5-4
NOx emissions during operation with the Xonon® combustor. Maximum 3-hour average NOx concentrations are reported for each day of the month. Data include NOx produced in both the combustion turbine and the HRSG duct burner.

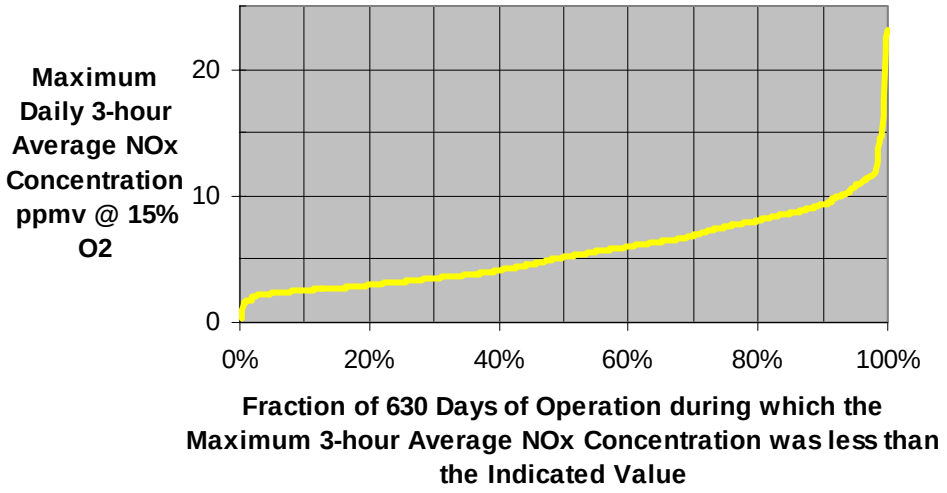

Figure 5-5
Distribution of Daily Maximum 3-hour Average NOx Concentrations over the 27 Months of Xonon® -equipped Combustor Operation.

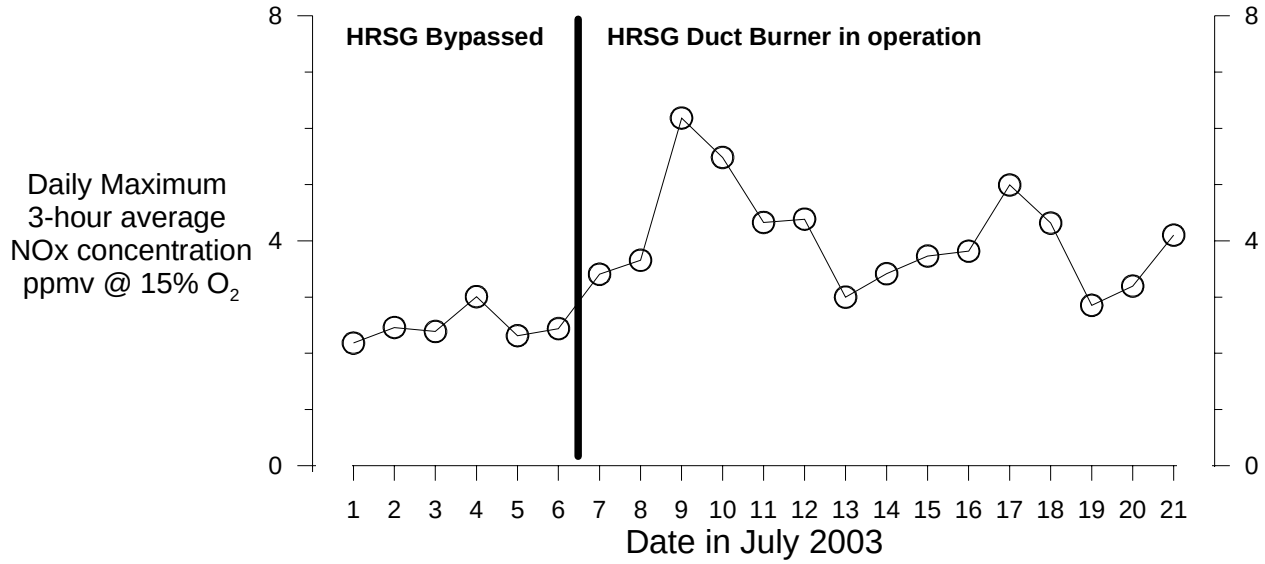

Figure 5-6
Reported daily maximum NOx emissions for operation without and with the HRSG duct burner in operation.
- Median for the six days of operation while bypassing the HRSG is 2.4 ppmv @ 15% O2.
- Median for the 15 remaining days of operation with the HRSG duct burner in operation is 3.8 ppmv @ 15% O2.

6
CONCLUSIONS

Sonoma Developmental Center (SDC) in Eldridge, California has employed a 1,400-kWe Kawasaki combustion turbine-generator in combined-heat-and-power service since 1993. The original turbine installed employed water injection for NOx control. This turbogenerator was replaced with a staged combustion (dry low-NOx) engine in 1998. A new turbogenerator equipped with Xonon® Cool Combustion was installed in 2002.

The Xonon® combustor employs catalytic surfaces to burn the fuel (without flame) at temperatures below those at which NOx forms. There are residual amounts of NOx formed in a pilot burner where a small amount of fuel is burned in a flame to raise the fuel/air mixture to the temperature at which the catalyst is active.

NOx emissions at the SDC installation were marginally reduced when the staged combustion turbogenerator replaced the water injection unit. NOx emissions were significantly reduced when the Xonon®-equipped turbogenerator was installed in 2002.

Data for 27 months of Xonon® combustor operation show that the NOx emissions of the turbogenerator and heat recovery steam generator (HRSG) duct burner combined have been consistently under 20 ppmv (as required by the site air emissions permit) and largely under 5 ppmv. When the HRSG/duct burner is bypassed (measured NOx coming from the combustion turbine only), NOx emissions were consistently below 3.0 ppmv and largely below 2.4 ppmv.

Campaign-style emissions measurements on a nearly identical Xonon®-equipped Kawasaki combustion turbine-generator in Santa Clara, California operating at greater than 98% load were verified by the U.S. EPA to be 1.13 ppmv NOx, 1.36 ppmv CO and 0.16 ppmv unburned hydrocarbons. These emissions levels are all below the standards developed by the California Environmental Protection Agency Air Emissions Board for generators in service January 1, 2007.

During the first 27 months of operation with the Xonon® combustor, the gas turbine maintenance outage rate was approximately 11%. These maintenance outages were largely for components other than the Xonon® combustion system. The outage rate associated with replacement of the Xonon® catalyst module (two replacements) was approximately 1%.

The original Xonon® catalyst module was replaced at approximately 4,500 hours. The second catalyst module logged more than 8,631 hours of operation. The third catalyst module was installed in November 2004 and logged 2,183 hours of operation up to the turbine failure in February 2005. Replacement costs were included in the maintenance contract that SDC has with Kawasaki.