Appendix B
Supporting Material for BACT Review For Electrical Generation Technologies

I. INTRODUCTION

Discussed in detail below are recommended emission levels for electrical generation sources using small gas turbines (rated at less than 50 MW in size), reciprocating engines using fossil fuel, and gas turbines / reciprocating engines using waste gas. The discussion below is based upon the requirements for determining Best Available Control Technology (BACT) in California and that BACT in California is equivalent to federal requirements for lowest achievable emission rate (LAER). BACT is generally specified as the most stringent emission level of these three alternative minimum requirements: 1) the most stringent emission control contained in any approved State Implementation Plan (SIP); 2) the most effective control achieved in practice; and 3) the most efficient emission control technique found by the district to be both technologically feasible and cost effective.

This appendix provides the basis for the information presented in Chapter V (BACT for Electrical Generation Technologies). This appendix addresses BACT determinations for oxides of nitrogen (NOx), volatile organic compounds (VOC), carbon monoxide (CO), and particulate matter (PM).

For the most effective control achieved in practice, examples were provided of emission levels specified in preconstruction permits issued by California districts and other states, and the most stringent emission levels achieved in practice. For each example cited, the following information is included: the name of the facility the equipment is located at, the applicable California district or State making the determination, a description of the basic equipment, and the method of control used to reduce emissions. In addition, for the control techniques required, the status of the permit (authority to construct/permit to construct or permit to operate) and the emission levels established by the permitting agency are provided. Similarly, for emission levels achieved in practice, the date the emission test was conducted and the measured emission levels are provided. The emissions testing was conducted with Air Resources Board (ARB) or United States Environmental Protection Agency (U.S. EPA) approved test methods.

Information was obtained primarily from California district rules, personal contacts with California and out-of-state regulatory agency staff, vendors of basic equipment, and control technology vendors. Additional important sources of information were guidelines for BACT from the following districts, available on the applicable district's website: Bay Area Air Quality Management District (BAAQMD), San Diego County Air Pollution Control District (SDCAPCD), and the South Coast Air Quality Management District (SCAQMD). Finally, BACT determinations listed in the California Air Pollution Control Officers Association (CAPCOA) BACT Clearinghouse, San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) Clearinghouse, and the U. S. EPA Reasonably Available Control Technology (RACT)/BACT/LAER Clearinghouse were reviewed.

Based upon the information collected for the most stringent emission control contained in any approved SIP and the most effective control achieved in practice, a recommended emission level is provided. These recommendations serve as a starting point for districts to make case-by-case BACT determinations. As discussed below, there are additional emission control technologies that the ARB staff believes are technologically feasible, and district staff should consider these technologies in BACT determinations for electrical generation technologies.

II. GAS TURBINES LESS THAN 50 MW

A. Control Technologies

Many of the control techniques applicable to small gas turbines have been described in the ARB report: Guidance for Power Plant Siting and Best Available Control Technology, September 1999 (referred to as the "ARB Power Plant Guidance" in the rest of this appendix). Refer to this report for a detailed description of the control technologies discussed below.

B. Current SIP Control Measures

There are several SIP control measures specifying reductions in NOx emissions from gas turbines. The most stringent of these measures has been adopted by the SCAQMD and the Antelope Valley Air Pollution Control District (AVAPCD) with NOx emission standards based upon size, annual operating hours, and control system used. The SCAQMD and AVAPCD requirements vary from 25 ppm for the smallest turbines (rated at 0.3 to 2.9 MW) to 9 ppm for turbines with a rating larger than 2.9 MW.

C. Control Techniques Required As BACT

1. BACT Guidelines

To assist applicants in meeting BACT requirements, the BAAQMD, SDCAPCD, and SCAQMD have published BACT guidelines. For gas turbines, both BAAQMD and SCAQMD have separate BACT levels for small gas turbines (rated at less than 3 MW in the SCAQMD and rated at less than 2 MW in BAAQMD) and for larger gas turbines (rated at 3 MW and larger up to 50 MW). For the small gas turbines, both the BAAQMD and SCAQMD guidance specify 9 ppmvd at 15 percent

O_2 for NOx (BAAQMD Guidelines also identify as technically feasible and cost effective a 5 ppmvd at 15 percent O_2 for NOx based upon the application of catalytic combustion or high temperature SCR system with combustion modifications). In addition, the SCAQMD guidance specifies 10 ppmvd at 15 percent O_2 for CO. For larger turbines, the most stringent requirements specified in these guidelines are 5 ppmvd at 15 percent O_2 for NOx, 2 ppmvd at 15 percent O_2 for VOC, and 6 ppmvd at 15 percent O_2 for CO. These emission levels are consistent with the 1999 ARB Power Plant Guidance for simple cycle gas turbines rated at 50 MW or larger.

2. BACT Determinations

Table B-1 lists examples of the most stringent emission levels required by California districts or other states, for emissions of NOx, VOC, CO, and if applicable, ammonia specified in preconstruction permits for 19 gas turbine based electrical generation facilities.

The gas turbines used in these facilities range in size from the Kawasaki turbine that can generate up to 1.5 MW to a General Electric LM5000 turbine generating up to 49 MW. All of these facilities use natural gas as the primary fuel, although a few facilities are allowed to use an alternative liquid fuel. Many of these facilities have combined heat and power (CHP) applications (identified in the description of basic equipment by the inclusion of a heat recovery steam generator). The California Institute of Technology or Cal Tech facility is the only combined-cycle power configuration listed in Table B-1.

NOx control methods include techniques that minimize emissions and post combustion technologies. The techniques that minimize emissions include Xonon (a catalytic combustion technology that can achieve levels reached by post combustion systems), low NOx combustors, and water/steam injection. Post combustion systems such as selective catalytic reduction (SCR) and SCONOX have been used to achieve the lowest emission levels required by recent BACT determinations. Typically, BACT levels are satisfied with a combination of these technologies. Overall, SCR is the most common technology used to satisfy BACT levels, and it has been proposed to satisfy BACT for a turbine as small as a 3.5 MW Solar Centaur 40. As discussed below, both the Xonon and SCONOX technology have been used on a more limited basis.

Oxidation catalyst has been the control device of choice to reduce the emissions of both VOC and CO from gas turbines. The list of recent BACT determination indicates that oxidation catalyst has been required for all but the smallest electrical generation resources. In addition, one of the advantages of the SCONOX and Xonon technologies is its ability to reduce emissions of VOC and CO in addition to NOx.

Table B-1
Emission Control Requirements for Combustion Turbine Electrical Generation Less Than 50 MW

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Status	Permit Limit (ppmvd @ 15%O2) One hour average			
					NOX	VOC	CO	NH3
Alliance Colton--Century	SCAQMD	(4) 10.5 MW General Electric 10B1 (116 MMBtu/hr) generating total of 40 MW	XONON or selective catalytic reduction (SCR)/CO oxidation catalyst	PTC 3/01	5	2	6	5 if SCR
Alliance Colton--Drews	SCAQMD	(4) 10.5 MW General Electric 10B1 (116 MMBtu/hr) generating total of 40 MW	XONON or SCR/CO oxidation catalyst	PTC 3/01	5	2	6	5 if SCR
B. Braun Medical (previously McGraw) -- Irvine	SCAQMD	Solar Centaur T-4701 (3.3 MW and 44.6 MMBtu/hr) and GS-4000 (2.8 MW and 42 MMBtu/hr) with heat recovery steam generator equipped with duct burner and generating a total of 6 MW	Water injection / SCR / oxidation catalyst	PTC 9/93	9**	NA	10**	10**
California Institute of Technology, Pasadena	SCAQMD	Solar Centaur 50-TS900 generating 4.2 MW (58.9 MMBtu/hr) with heat recovery steam generator and steam turbine for total of 5 MW	Water injection / SCR	PTC 9/96	9	lb/hr limits	lb/hr limits	20
CalPeak Power--Buttonwillow	SJVUAPCD	(2) 24.7 MW Pratt & Whitney FT-8 Twin Pac (246 MMBtu/hr) generating total of 49 MW	DLN combustors / SCR / oxidation catalyst	ATC 4/01	3.4*	2*	NA	10
CalPeak Power--Panoche	SJVUAPCD	(2) 24.7 MW Pratt & Whitney FT-8 Twin Pac (246 MMBtu/hr) generating total of 49 MW	Dry Low NOx (DLN) combustors / SCR / oxidation catalyst	ATC 4/01	3.4*	2*	NA	10
Double C Limited--Oilfield	SJVUAPCD	General Electric LM2500 gas turbine (222 MMBtu/hr) with heat recovery steam generator producing 24 MW	Steam injection / SCR / oxidation catalyst	PTO 7/98	4.5 *	NA	51*	20

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Table B-1
Emission Control Requirements for Combustion Turbine Electrical Generation Less Than 50 MW

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Status	Permit Limit (ppmvd @ 15%O2) One hour average			
					NOX	VOC	CO	NH3
Genetics Institute--Andover, Massachusetts	Massachusetts	Solar Taurus 60 generating 5 MW (65 MMBtu/hr) with heat recovery steam generator equipped with duct burner	DLN combustors / SCONOX	ATC 9/98	2.5 NG / 15 oil	NA	5	NA
Genxon Power Systems--Santa Clara	BAAQMD	Kawasaki M1A-13 with Xonon generating 1.5 MW (22.9 MMBtu/hr)	XONON	PTO 4/99	5*	5*	10*	NA
High Sierra Limited--Oilfield	SJVUAPCD	General Electric LM2500 gas turbine (222 MMBtu/hr) with heat recovery steam generator producing 25 MW	Steam injection / SCR / oxidation catalyst	PTO 6/98	4.5	NA	51	20
LADWP--Valley	SCAQMD	General Electric LM6000 enhanced Sprint gas turbine (466 MMBtu/hr) generating 47.4 MW	Water/steam injection-SCR and oxidation catalyst	ATC 5/01	5	2	6	5
Live Oak Limited--Oilfield	SJVUAPCD	General Electric LM5000 gas turbine (460 MMBtu/hr) with heat recovery steam generator producing 49 MW	Steam injection / SCR / oxidation catalyst	ATC 99	3.6*	0.6	11*	20
Northern California Power--Lodi	SJVUAPCD	General Electric LM5000 gas turbine (460 MMBtu/hr) producing 49 MW	Steam injection / SCR / oxidation catalyst	ATC 3/99	3*	none	200*	25
NRG Energy Center Round Mountain, LLC--Oilfield	SJVUAPCD	General Electric LM6000 enhanced Sprint gas turbine (466 MMBtu/hr) with heat recovery steam generator equipped with duct burner generating 47.4 MW	Water/steam injection-SCR and oxidation catalyst	ATC 4/01	2*; 2.5**	2	lb/hr limit	5

Table B-1
Emission Control Requirements for Combustion Turbine Electrical Generation Less Than 50 MW

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Status	Permit Limit (ppmvd @ 15%O2) One hour average NOX	VOC	CO	NH3
Redding Power--Redding	Shasta Co. APCD	Alstom GTX 100 (407 MMBtu/hr) with heat recovery steam generator producing 43 MW	SCONOX	ATC 3/01	2.5	1.4	6	NA
Saint Agnes Medical Center--Fresno	SJVUAPCD	(2) Solar Centaur 40 generating 3.5 MW (58.9 MMBtu/hr) producing a total of 7 MW	DLN combustors / SCR	ATC 2/00	5	6	50	10
San Joaquin Cogen--Lathrop	SJVUAPCD	General Electric LM5000 gas turbine (460 MMBtu/hr) with heat recovery steam generator producing 48.6 MW	Steam injection / SCR / oxidation catalyst	ATC 99	3.8**	NA	12**	20
University of California, San Diego	San Diego Co. APCD	(2) Solar Titan generating 12.9 MW (148.6 MMBtu/hr) for total of 25 MW	SoLoNox / SCONOX	ATC 1/01	2.5	NA	5	NA
University of California, San Francisco	BAAQMD	(2) Solar Taurus 60 generating 5 MW (76 MMBtu/hr) with heat recovery steam generator equipped with duct burner for total of 10 MW	SCR /oxidation catalyst	PTO 1998	5 NG / 8 oil*	0.01 lb/MMBtu	10*	10

* 3-hr average
** 15 minute rolling average

A review of the NOx emission levels shown in Table B-1 indicate that the most stringent emission limits are for gas turbines rated at 10.5 MW or larger. Recent determinations have required combustion turbines larger than 10.5 MW to achieve NOx ppmvd levels ranging from 2 to 4.5 ppmvd at 15 percent O_2 or better, based on averaging periods of up to a three-hour rolling average. The most stringent level required in a preconstruction permit is for the NRG Energy Center Round Mountain facility located in the San Joaquin Valley. The NOx limit was 2 ppmvd at 15 percent O_2 averaged over three hours. Ammonia slip for this facility was set at 5 ppmvd at 15 percent O_2. The determination is for a General Electric LM6000 enhanced sprint gas turbine with a heat recovery steam generator and equipped with water or steam injection, SCR, and oxidation catalyst. In addition, Northern California Power in Lodi was permitted at 3 ppmvd at 15 percent O_2 averaged over three hours for NOx. The facility consists of a General Electric LM5000 gas turbine operated in a simple-cycle mode and equipped with steam injection, SCR, and oxidation catalyst.

Conversely, except when SCONOX is specified as the NOx emission control system, smaller units have been required to achieve 5 ppm at 15 percent O_2. Several facilities have been permitted at this level. These include the Saint Agnes Medical Center, the University of California, San Francisco (UCSF) and two projects for Alliance Colton. The Saint Agnes Medical Center generating facility consists of a Solar Centaur 40 (3.5 MW) equipped with dry low NOx combustors and SCR. The unit at UCSF uses a Solar Taurus 60 (5 MW) with heat recovery and is equipped with water injection and SCR. Finally, the Alliance Colton facilities are based upon a General Electric 10B1 (10 MW) operated in simple cycle mode and equipped with either Xonon or SCR. With regard to ammonia slip, the most stringent level established in a preconstruction permit is 10 ppmvd at 15 percent O_2. For facilities equipped with SCONOX, turbines have been required to achieve 2.5 ppm at 15 percent O_2.

With regard to VOC and CO, the most stringent level appearing in a preconstruction permit is 2 ppmvd at 15 percent O_2 for VOC and 6 ppmvd at 15 percent O_2 for CO. This requirement has been applicable to facilities with total generating capacity of more than 5 MW and is consistent with the 1999 ARB Power Plant Guidance for power plants using gas turbines rated at more than 50 MW and are achievable using oxidation catalyst.

D. Emission Levels Achieved in Practice

Table B-2 lists examples of the most stringent emission levels achieved, based upon emission testing, for NOx, VOC, CO, and ammonia for nine power plants using combustion turbines that are rated at less than 50 MW. The emission data is for natural gas--a couple of facilities were also tested with backup fuels. In general, emission measurement results were available for a broad range of gas turbine sizes - 1.5 MW to 49 MW. For the gas turbines that are rated at less than

Table B-2
Emission Source Test Results for Combustion Turbine Electrical Generation Less Than 50 MW

Facility Name	District / State	Description of Basic Equipment	Method of control	Date Tested	Measured Concentrations (ppmvd @ 15%O2) NOX	VOC	CO	NH3
California Institute of Technology, Pasadena	SCAQMD	Solar Centaur 50-TS900 generating 4.2 MW (58.9 MMBtu/hr) with heat recovery steam generator and steam turbine for total of 5 MW	Water injection / SCR	1/00	4.2	not measured	46	NA
Double C Limited--Oilfield	SJVUAPCD	General Electric LM2500 gas turbine (222 MMBtu/hr) with heat recovery steam generator producing 24 MW	Steam injection / SCR / oxidation catalyst	2/01	2.4	not measured	14.5	not measured
Federal Cold Storage Cogeneration	SCAQMD	General Electric LM2500-M-2 gas turbine (222 MMBtu/hr) and steam turbine producing 32 MW	Water injection/SCONOX	CEM data since 1995	2	not measured	1	NA
Genetics Institute--Andover, Massachusetts	Massachusetts	Solar Taurus 60 generating 5 MW (65 MMBtu/hr) with heat recovery steam generator equipped with duct burner	DLN / SCONOX	2/00 NG 50% load	0.27	NA	0	NA
				2/00 NG 65% load	0.34	NA	0	NA
				2/00 NG 85% load	0.42	NA	0	NA
				2/00 NG 100% load	1.42	NA	0	NA
				2/01 oil 50% load	1.28	NA	0	NA
				2/01 oil 65% load	2	NA	0	NA
				2/01 oil 85% load	2.06	NA	0	NA
				2/01 oil 100% load	5.93	NA	0	NA

Table B-2
Emission Source Test Results for Combustion Turbine Electrical Generation Less Than 50 MW

Facility Name	District / State	Description of Basic Equipment	Method of control	Date Tested	Measured Concentrations (ppmvd @ 15%O2)			
					NOX	VOC	CO	NH3
Genxon Power Systems--Santa Clara	BAAQMD	Kawasaki M1A-13 with Xonon generating 1.5 MW (22.9 MMBtu/hr)	XONON	12/98	2.9	2.7	3.9	NA
High Sierra Limited--Oilfield	SJVUAPCD	General Electric LM2500 gas turbine (222 MMBtu/hr) with heat recovery steam generator producing 25 MW	Steam injection / SCR / oxidation catalyst	3/01	3.6	<0.3	17	<2
Live Oak Limited--Oilfield	SJVUAPCD	General Electric LM5000 gas turbine (460 MMBtu/hr) with heat recovery steam generator producing 49 MW	Steam injection / SCR / oxidation catalyst	4/00	2	<1	1.3	10
Northern California Power--Lodi	SJVUAPCD	General Electric LM5000 gas turbine (460 MMBtu/hr) producing 49 MW	Steam injection / SCR / oxidation catalyst	7/00	2.75	not measured	11.5	24.5
University of California, San Francisco	BAAQMD	(2) Solar Taurus 60 generating 5 MW (76 MMBtu/hr) with heat recovery steam generator equipped with duct burner for total of 10 MW	SCR /oxidation catalyst	5/98 turbine S-9 NG	4	<0.6	0.6	3.2
				5/98 turbine S-11 NG	4.6	<0.6	1.1	3.3
				5/98 turbine S-9 oil	7.8	<1.1	0.6	20.1
				5/98 turbine S-11 oil	7.9	<1.1	1.1	16.1

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10.5 MW, the following emission levels have been achieved: NOx emissions of 2 to 4.6 ppmvd at 15 percent O_2 (Xonon and SCONOX for the low end of range and SCR at the higher end of the range), trace levels of VOC emissions (Xonon less than 3 ppmvd at 15 percent O2), and CO emissions of 1 to 46 ppmvd at 15 percent O_2. For the larger gas turbines, the following emission levels have been achieved: NOx emissions of 2 to 3.6 ppmvd at 15 percent O_2 or better, trace levels of VOC emissions, and CO emissions of 1 to 14.5 ppmvd at 15 percent O_2.

For the gas turbines that are rated at less than 10.5 MW, two generating facilities have achieved the most stringent NOx emission level of 5 ppmvd at 15 percent O_2. These include the UCSF discussed above and the generating facility at CalTech, Pasadena. The unit at CalTech consists of a Solar Centaur 50 (4.6 MW) turbine operated in a combined cycle mode and the turbine is equipped with water injection and SCR. In addition, the UCSF facility is also equipped with oxidation catalyst. With the catalyst, the UCSF facility has reduced VOC emissions to the detection level and CO emissions are at 1 ppm—well under the 1999 ARB Power Plant Guidance levels of 2 ppmvd at 15 percent O2 and 10 ppmvd at 15 percent O_2, respectively.

For the larger gas turbines, the lowest level achieved in practice is for the Northern California Power facility in Lodi, which has operated since early-1999. Based upon CEM data and annual inspections, the unit has met the 3 ppmvd NOx limit since startup. The latest compliance test indicated NOx emissions were below 3 ppmvd at 15 percent O_2 and emissions of CO were measured at about 12 ppmvd at 15 percent O_2. However, this level was achieved with an ammonia slip above 10 ppmdv at 15 percent O_2.

Three other facilities in the San Joaquin Valley have been permitted at NOx level between 3.6 to 4.5 ppmvd at 15 percent O_2, based upon a 3-hour average. These facilities are Live Oak Limited, Double C Limited, and High Sierra Limited. Double C Limited and High Sierra Limited consists of a General Electric LM2500 turbine (25 MW) and heat recovery steam generator. Live Oak Limited consists of a General Electric LM5000 turbine (49 MW) and heat recovery steam generator. All three facilities produce steam for use at an oilfield, and are equipped with SCR and oxidation catalyst. The Live Oak Limited facility has consistently maintained NOx emission levels below 3 ppmvd at 15 percent O_2 since starting up in 2000. Both the Double C Limited and High Sierra Limited facilities were permitted at a higher NOx limit, 4.5 ppmvd at 15 percent O_2, but have typically been between 2.5 to 3.5 ppmvd at 15 percent O_2 based upon three years of annual testing. Finally, the latest compliance test for Live Oak Limited also indicated VOC and CO emissions were near or below the detection level.

Xonon's only commercial application is at the Genxon Power Systems facility on a 1.5 MW Kawasaki turbine. The Kawasaki turbine has now operated for 8,000 hours. Compliance tests indicated the NOx emissions are below 3 ppmvd at 15 percent O_2.

SCONOX has been implemented on two turbines, one turbine is rated at 5 MW and the other at 25 MW. The 25 MW turbine at the Federal Cold Storage cogeneration facility has operated for six years, achieving NOx levels of less than 2 ppmvd at 15 percent O_2 when firing natural gas. The 5 MW turbine at the Genetics Institute has operated mainly on fuel oil with some difficulty. However, when the turbine operates for long periods of time using oil, which appears to be the normal operating scenario, the SCONOX technology has experienced masking problems which reduces the effectiveness of the technology in reducing NOx emissions. The masking is reversible, but requires cleaning of the catalyst, and therefore shutdown of the turbine. EmeraChem, (formerly known as Goal Line Environmental Technologies), the developer of the SCONOX technology, has since made modifications to the SCONOX systems at Genetics Institute such that oil usage no longer adversely affects the SCONOX system. After some initial startup problems, the Genetics facility has been reported to have no operating difficulties when operating on natural gas and has satisfied all applicable emission limits. Additional discussion on the applicability of SCONOX is discussed in the next section.

E. More Stringent Control Techniques

1. SCONOX

As can be seen in Tables B-1 and B-2, the SCONOX technology has operating experience at two facilities, the Federal Cold Storage Cogeneration facility on a General Electric LM2500 gas turbine rated at 25 MW in combined cycle mode for total generation of 32 MW and the Genetics Institute facility on a gas turbine rated at 5 MW. The technology has operated for six years at the Federal Cold Storage Cogeneration facility and in that time period, the technology has been improved such that NOx emissions are typically between 1-2 ppmvd at 15 percent O_2. The ARB staff, through its Equipment Precertification Program, has verified the emissions of NOX as low as 2 ppmvd at 15 percent O_2 over a three-hour rolling average for the Federal Cold Storage Cogeneration facility. For the Genetics Institute facility, as discussed above, after some initial operational problems, which required fine-tuning of the operation of the turbine and the control system, the SCONOX technology has operated well when the turbine uses natural gas. When the turbine uses oil, EmeraChem has apparently resolved its operating issues.

At the University of California, San Diego, two turbines rated at 12.5 MW equipped with the SCONOX technology have recently become operational. The July 2001 compliance test indicates NOx emissions levels are below 1 ppmvd at 15 percent O_2 for both turbines. However, prior to the compliance test, the facility was operating under a variance because the facility could not meet its permit limits within the commissioning period (90 days) allocated for shakeout and fine-tuning the facility's operation. Finally, SCONOX is also proposed for the Redding Power facility in Shasta, which would be the largest turbine the technology has been installed to this date.

The SCONOX technology has advantages over SCR in that it can achieve very low NOx emission levels without the emissions of ammonia. In addition, the technology also reduces VOC and CO emissions without the need of adding another control device. Because the technology has not been demonstrated for all sizes of turbines, the ARB staff is not considering the SCONOX technology for the purposes of establishing guideline levels. However, district staff should continue to consider SCONOX in BACT determinations.

2. Xonon

In the 1999 ARB Power Plant Guidelines report, the Xonon technology was identified as a developing technology. Since then, the 1.5 MW Kawasaki gas turbine equipped with the Xonon technology has operated over 8,000 hours and during that time period, the turbine has satisfied it NOx emission limit of 5 ppmvd. Catalytica Combustion Systems has applied to the ARB's Equipment and Process Precertification Program to verify that the Kawasaki turbine M1A-13X equipped with Xonon demonstrates emissions of 2.5 ppmvd at 15 percent O_2 for a one-hour rolling average at 98 percent or greater operating load based on design capacity.

While the Xonon technology is demonstrated for the Kawasaki gas turbine, it is unclear how well the technology can be applied to larger gas turbines. Catalytica Combustion Systems, the manufacturer of Xonon, is in the process of demonstrating the technology on larger gas turbines. A review of Table B-1 indicates that proponents for two facilities using turbines rated at 10 MW are proposing to use the Xonon technology. Additionally, Xonon is also being proposed for use on a large gas turbine (greater than 50 MW).

F. Discussion and Recommendation

The discussion below recommends BACT levels, on a ppmvd basis, based upon the electrical generating capacity of the turbine. For the larger turbines, BACT levels are based upon whether the turbine is used in either a combined cycle or simple cycle application. In addition, these recommendations reflect the Board’s direction that gas turbine based electrical generation be further categorized into combined-cycle and simple-cycle applications.

Finally, the recommendations discussed below are largely based upon levels achieved in practice. Consequently, district permitting staffs are encouraged to evaluate the SCONOX or Xonon technologies to determine whether either technology is a feasible and cost effective option for a specific application.

1. Gas Turbines Less Than 3 MW

The most stringent BACT levels for gas turbines rated at less than 3 MW is expressed in the SCAQMD and the BAAQMD BACT Guidelines (achieved in practice levels). The guidelines specify BACT at 9 ppmvd at 15 percent O_2 for NOx, 5 ppmvd at 15 percent O_2 for VOC, and 10 ppmvd at 15 percent O_2 for CO. Ammonia slip was also limited to 9 ppmvd at 15 percent O_2. While the Kawasaki turbine (1.5 MW) equipped with the Xonon combustors has achieved NOx levels of 2-3 ppmvd at 15 percent O_2, the ARB staff is not recommending this emission level until the Xonon technology is available for a wider range of turbines. Based upon the above, the ARB staff recommends BACT levels for gas turbines rated at less than 3 MW to be consistent with these guidelines for such gas turbines.

2. Gas Turbines from 3 MW to 50 MW

a. Combined-Cycle Applications

For gas turbines in combined-cycle/heat recovery steam generator applications, there are a number of facilities permitted at NOx levels of 3 ppmvd at 15 percent O_2 or less. The most stringent level required in a preconstruction permit is for the NRG Energy Center Round Mountain facility located in the San Joaquin Valley. The NOx emission limit was 2 ppmvd at 15 percent O_2 averaged over three hours. The determination is for a General Electric LM6000 enhanced sprint gas turbine with heat recovery steam generator and equipped with water or steam injection, SCR, and oxidation catalyst.

The most stringent NOx BACT level achieved in practice has been achieved with SCONOX. The Genetics Institute facility in Massachusetts and the Federal Cold Storage Cogeneration facility, previously discussed in the 1999 Power Plant Guidance, have demonstrated levels of less than 2 ppmvd at 15 percent O_2. The Genetics facility consists of a Solar Taurus 60 turbine equipped with SCONOX and when firing natural gas, NOx emissions are less than 2 ppmvd NOx at 15 percent O_2. Similarly, the Federal Cold Storage Cogeneration facility has demonstrated levels of less than 2 ppmvd at 15 percent O_2 since 1996, based upon continuous emissions data collected over that period. This facility consists of a General Electric LM2500 gas turbine operating in a combined cycle configuration and generating 32 MW. The gas turbine utilizes water injection in conjunction with SCONOX. In addition, ARB staff, through its Equipment Precertification Program, has verified NOX emissions as low as 2 ppmvd at 15 percent O_2 over a three-hour rolling average for the Federal Cold Storage Cogeneration facility. As discussed above SCONOX has not been demonstrated for all sizes of turbines.

Similar levels have also been achieved with SCR. For example, the Live Oak Limited facility has achieved a NOx emission level of 2.5 ppmdv at 15 percent O_2.

This facility consists of a General Electric LM5000 gas turbine and heat recovery steam boiler. Emissions are abated with a combination of steam injection and SCR. With regard to ammonia slip, the facility emits less than 10 ppmdv at 15 percent O_2.

With regard to VOC, CO, and ammonia, the most stringent level appearing in a preconstruction permit is 2 ppmvd at 15 percent O_2 for VOC, 6 ppmvd at 15 percent O_2 for CO and 5 ppmvd at 15 percent O_2 for ammonia. The Live Oak facility has achieved these levels for VOC and CO since early 2000 and the UCSF facility has achieved these levels since 1998. The UCSF facility is also equipped with an oxidation catalyst. Additionally, these levels are consistent with the 1999 ARB Power Plant Guidance for gas turbines rated at 50 MW or larger and are achievable using an oxidation catalyst.

ARB staff recommends a BACT level of 2.5 ppmvd at 15 percent O_2 for NOx, three-hour rolling average, 2 ppmvd at 15 percent O_2 for VOC, three-hour rolling average, 6 ppmvd at 15 percent O_2 for CO, three-hour rolling average, and 10 ppmvd at 15 percent O_2 for NH3. However, district permitting staff are encouraged to evaluate the technical feasibility and cost effectiveness of more stringent technologies, including the SCONOX or Xonon technologies, as part of the case-by-case BACT determination for power generating projects.

b. Simple-Cycle Applications

The most stringent NOx emission level required in a preconstruction permit is for the Northern California Power facility located in Lodi. The determination was for 3 ppmvd at 15 percent O_2 for NOx averaged over three hours. However, this level was based upon an ammonia slip above 10 ppmdv at 15 percent O_2. The determination is for a General Electric LM5000 gas turbine equipped with steam injection, SCR, and oxidation catalyst. Several other facilities have been permitted at 5 ppmvd at 15 percent O_2 for NOx, three-hour rolling average, 2 ppmvd at 15 percent O_2 for VOC, three-hour rolling average, and 6 ppmvd at 15 percent O_2 for CO, three-hour rolling average. In addition, for these projects, the NH3 level have been set between 5 – 10 ppmvd at 15 percent O_2.

The lowest level achieved in practice is for Northern California Power facility in Lodi, mentioned above, which has operated since early-1999. Based upon CEM data and annual inspections, the unit has continued to meet the 3 ppmvd NOx permit limit. Since startup, the facility has been cited once by the district for exceeding the ammonia slip limit and, as discussed above, these levels are higher than specified for similar projects. The latest compliance test indicated NOx emissions were below 3 ppmvd at 15 percent O_2 and emissions of CO were measured at about 12 ppmvd at 15 percent O_2. Other facilities have been proposed to meet a 3.4 ppmvd at 15 percent O_2 level while also limiting ammonia slip to 10 ppmdv at 15 percent O_2. The ARB staff will continue to evaluate the feasibility of achieving a 3 ppmvd NOx level with minimal ammonia slip. The lowest NOx level achieved in a simple cycle application was 5 ppmdv at 15 percent O_2, where the ammonia slip was also limited to 10 ppmdv at 15 percent O_2. The Carson Energy facility in Sacramento, previously discussed in the 1999 Power Plant Guidance, has satisfied these levels since beginning operation in 1995. The Carson Energy facility consists of a General Electric LM6000 turbine operated in simple cycle mode.

With regard to VOC and CO, the Carson Energy facility has demonstrated levels of 2 ppmvd at 15 percent O_2 for VOC and 6 ppmvd at 15 percent O_2 for CO. These levels are consistent with the 1999 ARB Power Plant Guidance for power plants using gas turbines rated at 50 MW or larger and are achievable using oxidation catalyst.

Based on the above, the ARB staff recommends a BACT level of 5 ppmvd at 15 percent O_2 for NOx, three-hour rolling average, 2 ppmvd at 15 percent O_2 for VOC, three-hour rolling average, 6 ppmvd at 15 percent O_2 for CO, three-hour rolling average, and 10 ppmvd at 15 percent O_2 for NH3. Again, district permitting staffs are encouraged to evaluate the technical feasible and cost effectiveness of more stringent BACT levels.

III. NON-EMERGENCY RECIPROCATING ENGINES USING FOSSIL FUELS

As discussed below, some districts are beginning to develop BACT requirements that are fuel neutral. For example, the SCAQMD BACT Guidelines for minor sources specifies BACT for NOx emissions from reciprocating engines used in nonemergency applications as 0.15 g/bhp-hr. Based upon this approach, the BACT levels can only be satisfied by a well controlled natural gas fueled reciprocating engine. At this time, diesel fueled engines cannot achieve this emission level. Consequently, the discussion below focuses on the emission levels achieved by natural gas fueled reciprocating engines.

A. Control Technologies

The combustion of natural gas in reciprocating engines results in emissions of the following criteria pollutants: NOx, CO, VOC, PM, and sulfur oxides (SOx). For natural gas, the emissions of PM and SOx result from the amount of sulfur in the fuel. The sulfur concentration in "pipeline quality" natural gas is regulated by the Public Utilities Commission. Consequently, no recommendations will be provided for PM and SOx emissions. However, staff will recommend that a PM standard be added in the event diesel-fueled engines are able to achieve the same emission levels as natural gas fueled reciprocating engines. This PM level is consistent with the technology requirements of the ARB diesel risk management guidance.

For the remaining pollutants, the pollutant of primary concern from stationary reciprocating engines is NOx, a criteria pollutant that reacts in the atmosphere to form ozone which is a significant air pollution problem in California. To reduce NOx emissions from natural gas fueled reciprocating engines, BACT levels are typically achieved with post-combustion controls, including nonselective catalytic reduction (NSCR) or three-way catalyst for rich-burn engines or SCR for lean-burn engines. The major difference between rich-burn and lean-burn engines is in the amount of excess air used for combustion. Rich-burn engines use nearly equal mixture of air and fuel while lean-burn engines use significantly more air than fuel.

Similarly, BACT levels for CO and VOC emissions are also based upon post-combustion controls. Three-way catalyst is used to reduce CO and VOC emissions from rich-burn engines and oxidation catalyst is used to reduce CO and VOC emissions from lean-burn engines.

A detailed description of both the SCR or CO/VOC oxidation catalyst technologies are given in the 1999 ARB Power Plant Guidance Report. A description of the NSCR technology is given below.

1. Nonselective Catalytic Reduction

The NSCR technology or three-way catalyst, which is the same technology used to reduce emissions from motor vehicle gasoline engines and has been used on rich-burn stationary engines for over 15 years, employs a catalyst that reduces the emissions of NOx, CO, and VOC. Three-way catalyst promotes the chemical reduction of NOx in the presence of CO and VOC to produce oxygen and nitrogen. The three-way catalyst also contains materials that promote the oxidation of VOC and CO to form carbon dioxide and water vapor. The standard catalyst typically achieves 90 percent reduction in NOx, 50 percent reduction in VOC, and 80 percent reduction in CO. A premium catalyst is able to achieve higher reductions in NOx--up to 99 percent. An electronic controller, which includes an oxygen sensor and feedback mechanism, is necessary to maintain the proper air/fuel ratio. The three-way catalyst system operates in a narrow air/fuel ratio band--operation outside the band can dramatically increase either NOx or CO emissions. In addition, the three-way catalyst technology achieves its optimal reduction within a certain temperature band.

B. Current SIP Control Measures

Several districts have adopted SIP control measures specifying reductions in NOx emissions from reciprocating engines. The most stringent of these measures has been adopted by SCAQMD, AVAPCD, and Ventura County Air Pollution Control District (VCAPCD). Both measures set emission standards for NOx, VOC, and CO.

The SCAQMD and AVAPCD requires reciprocating engines to meet the following emission standards: 36 ppmvd at 15 percent O_2 for NOx, 250 ppmvd at 15 percent O_2 for VOC, and 2,000 ppmvd at 15 percent O_2 for CO. Alternate levels, which are higher than the general requirement, for NOx and VOC are allowed, based upon the efficiency of the engine.

VCAPCD requirements for reciprocating engines vary based upon the type of engine and the standard can be satisfied by meeting an emission standard or achieving a specified percentage of emission reduction. The NOx emission standard varies from 25 to 80 ppmvd at 15 percent O_2. Similarly, the VOC standard varies from 250 to 750 ppmvd at 15 percent O_2 and the CO standard is 4,500 ppmvd at 15 percent O_2 for all type of engines. The emission reduction component applies to NOx only and reductions of 90 to 96 percent must be achieved, with the specific level based upon the engine type, to avoid the emission specific standard.

C. Control Techniques Required as BACT

1. BACT Guidelines

Of the districts with published BACT guidelines, the most stringent requirements are those requirements in the SCAQMD guidelines. For all stationary reciprocating engines used in a non-emergency application that are less than 2,064 bhp, the levels are set at 0.15 g/bhp-hr for NOx, 0.15 g/bhp-hr for VOC, and 0.6 g/bhp-hr for CO. For larger engines, the BACT guidelines specify standards for NOx (which allows higher emissions for engines with efficiencies greater than 33 percent) and CO (50 percent more stringent than the level specified for smaller engines) only. The only deviation from this BACT level is for landfill or digester gas fired engines, which will be discussed in the next section.

2. BACT Determinations

Table B-3 lists 17 examples of the most stringent emission controls required by California districts or other states, for emissions of NOx, VOC, CO, and if applicable, ammonia from reciprocating engines. The engines range in size from about 80 horsepower (hp) to over 4,000 hp.

The determinations listed in Table B-3 can be separated into determinations for rich-burn engines and determinations for lean-burn engines. For rich-burn engines, the use of three-way catalyst and air/fuel ratio controller has been used to achieve BACT levels of 0.15 g/bhp-hr (which is equivalent to about 9 ppmvd at 15 percent O_2) for NOx. The SCAQMD has specified 0.15 g/bhp-hr as BACT for NOx emissions from natural gas-fueled reciprocating engines used in nonemergency applications since 1998 and the next section provides a number of examples demonstrating that this level is achieved in practice. With regard to BACT levels for

Table B-3
Emission Control Requirements for Engines Using Fossil Fuel

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Status	Permit Limit (g/bhp-hr)*			
					NOX	VOC	CO	NH3
Aera Energy--Oilfield	SJVUAPCD	(5) 800 bhp Superior 8G-825 rich-burn engines or (3) 1478 bhp Waukesha 7042 GSI rich-burn engines driving natural gas compressors	3-way catalyst: Quick-Lid 3-DC74 and air/fuel ratio controller	ATC 1/01	0.071	0.069	0.603	NA
Claremont Club--Claremont	SCAQMD	(3) 86 bhp rich-burn engine cogeneration system	3-way catalyst: Miratech MN-11T-04F and air/fuel ratio controller	PTO 5/01	0.15	0.15	0.6	NA
College of the Desert--Palm Desert	SCAQMD	161 bhp Tecochill/Tecogen 74000LE rich-burn engine driving a compressor	3-way catalyst and air/fuel ratio controller	PTO 8/99	0.15	0.15	0.6	NA
Crestline Village Water District--Crestline	SCAQMD	94 bhp Ford LSG875 rich-burn engine driving a generator	3-way catalyst: Miratech MN-09-04F-D2 and air/fuel ratio controller	PTO 10/00	0.15	0.15	0.6	NA
Gill's Onions--Oxnard	Ventura Co. APCD	(3) 158 bhp Tecodrive 7400LE rich-burn engine driving refrigeration compressor; 250 bhp Waukesha F11 GSID rich-burn engine driving an air compressor; and 815 bhp Caterpillar G3512 rich-burn engine driving an air compressor	3-way catalyst and air/fuel ratio controller	ATC 4/98	9 ppmvd	27 ppmvd	62 ppmvd	NA
JST Energy LLC--Red Bluff	Tehama Co. APCD	(10) 3,928 bhp Wartsila 18V220SG lean-burn engine driving 2,926 KW generator for a total of 29 MW	SCR and oxidation catalyst: Miratech/Hug EM77/6 SCR and Oxicat oxidation catalyst	ATC 5/01	0.07 or 8 ppmvd	0.15 or 50 ppmvd	0.56 or 107 ppmvd	10 ppmvd

Table B-3
Emission Control Requirements for Engines Using Fossil Fuel

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Status	Permit Limit (g/bhp-hr)*			
					NOX	VOC	CO	NH3
Kaiser Permanente--Los Angeles	SCAQMD	(4) 171 bhp Tecodrive model 7400LE rich-burn engines use to drive two compressors / chillers that will provide cooling for the facility	3-way catalyst: Miratech MN-11T-04F and tecodrive air/fuel ratio controller	PTC 12/99	0.15	0.15	0.6	NA
Los Angeles County, Metropolitan Transit Authority--Los Angeles	SCAQMD	400 bhp Caterpillar G3408TA HCR rich-burn engine driving a compressor	3-way catalyst: Johnson Mathey QXH50-8 and air/fuel ratio controller	PTO 9/99	0.15	0.15	0.6	NA
NEO California Power LLC--Chowchilla	SJVUAPCD	(16) 4,157 bhp Deutz TBG632V16 lean-burn engine driving 3,100 KW generator for total of 49.6 MW	SCR and oxidation catalyst	ATC 3/01	0.07	0.15	0.1	10 ppmvd
NEO California Power LLC--Red Bluff	Tehama Co. APCD	(16) 3,928 bhp Wartsila 18V220SG lean-burn engine driving 2,926 KW generator for a total of 46.7 MW	SCR and oxidation catalyst: Miratech/Hug EM77/6 SCR and Oxicat oxidation catalyst	ATC 4/01	0.07	0.15	0.56	10 ppmvd
Saba Petroleum	Santa Barbara Co. APCD	747 bhp Waukesha 3521GSI rich-burn engine driving a compressor	3-way catalyst and air/fuel ratio controller	ATC 10/98	0.15	0.3	0.75	NA
SB Linden--Linden, NJ	NJDEP	3,130 bhp Waukesha 12VAT27GL lean-burn engine driving a pump	SCR and oxidation catalyst	ATC 12/96	50 ppmvd	58 ppmvd	76 ppmvd	10 ppmvd
Tosco-Ventura Pump Station--Ventura	Ventura Co. APCD	415 bhp Caterpillar SP321P001G379ASI rich-burn engine driving a pump	3-way catalyst: Quick-Lid and air/fuel ratio controller	ATC 12/97	9 ppmvd	100 ppmvd	1,000 ppmvd	NA

Table B-3
Emission Control Requirements for Engines Using Fossil Fuel

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Status	Permit Limit (g/bhp-hr)*			
					NOX	VOC	CO	NH3
Trillium USA--Los Angeles	SCAQMD	(3) 607 bhp Caterpillar G3412TAA rich-burn engine driving a compressor	3-way catalyst: Miratech EQ-700-XX-D2 and tecodrive air/fuel ratio controller	PTO 7/99	0.15	0.15	0.6	NA
Trillium USA--West Hollywood	SCAQMD	(3) 607 bhp Caterpillar G3412TAA rich-burn engine driving a compressor	3-way catalyst: Miratech EQ-700-XX-D2 and tecodrive air/fuel ratio controller	PTO 7/99	0.15	0.15	0.6	NA
Veterans Administration Medical Center--Brockton	Massachusetts	2,113 bhp Waukesha 8LAT27GL lean-burn engine driving a 1.5 MW generator	SCR and oxidation catalyst	ATC 4/01	0.15	0.6	0.16	5 ppmvd
Vintage Petroleum--Piru	Ventura Co. APCD	325 bhp Caterpillar 3406TA rich-burn engine driving a pump	3-way catalyst and air/fuel ratio controller	ATC 98	9 ppmvd	110 ppmvd	1,000 ppmvd	NA

* unless indicated otherwise (for example, ppmvd means parts per million by volume, dry at 15 pecent O2)

VOC and CO, recent determinations have limited VOC levels to 0.15 g/bhp-hr (about 25 ppmvd at 15 percent O_2) and CO levels to 0.6 g/bhp-hr (about 56 ppmvd at 15 percent O_2). Examples of engines permitted at these levels range in size from about 80 hp to about 1,500 hp.

San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) has recently established more stringent limits for NOx of 0.071 g/bhp-hr (5 ppmvd at 15 percent O_2), VOC at 0.069 g/bhp-hr (14 ppm at 15 percent O_2) and CO at 0.6 g/bhp-hr (70 ppm at 15 percent O_2)--see entry for Aera Energy in Table B-3. This determination is based upon a vendor guarantee for the emission level for either a 800 bhp Superior 8G-825 natural gas-fired engine or a 1,478 bhp Waukesha 7042 GSI engine, depending upon which engine is ultimately purchased. These engines would be driving natural gas compressors.

For lean-burn engines, recent emission limits in preconstruction permits have been based upon the use of SCR for NOx and oxidation catalyst for VOC and CO. As equipped, the emission limit for NOx has been set at 0.071 g/bhp-hr (5 ppm at 15 percent O_2), VOC at 0.15 g/bhp-hr (30 ppm at 15 percent O_2) and CO at 0.1 g/bhp-hr (12 ppm at 15 percent O_2). Ammonia slip is limited to 10 ppmvd at 15 percent O_2. These limits are for a 4,157 hp Deutz TBG632V16 lean burn engine equipped with SCR and oxidation catalyst.

D. Emission Levels Achieved in Practice

Table B-4 lists 23 examples from 14 different facilities of the most stringent emission levels achieved, based upon emission testing, for NOx, VOC, CO, and if applicable, ammonia for reciprocating engines at several facilities. Engines tested range in size from 86 hp engine up to 713 hp for rich-burn engines and over 3,000 hp for lean-burn engines. In most cases, the testing was done to satisfy annual compliance demonstration requirements. Consequently, some of the reciprocating engines have been tested for up to four years.

For the rich-burn engines, the test results shown in Table B-4 indicate that the 0.15 g/bhp-hr or 9 ppmvd at 15 percent O_2 NOx BACT level has been satisfied, in one instance, for over four years. Two 713 hp Caterpillar G398TAHC engines have operated since 1997 at Los Alamos Energy. Engine #2 has been in compliance with the NOx standard for four consecutive years, and the emissions of NOx have been below 5 ppmvd at 15 percent O_2 for the first three years. Conversely, engine #1 failed the 1998 compliance test. After a replacement of the catalyst, the engine passed the retest and has since satisfied subsequent compliance tests. In general, catalyst, with proper maintenance, is expected to have a two-year lifetime under continuous operation.

Table B-4
Emission Source Test Results for Engines Using Fossil Fuel

Facility Name	District / State	Description of Basic Equipment	Method of control	Date tested	Engine or test #	Measured Concentrations (ppmvd @ 15%O2)*		
						NOX	VOC	CO
Claremont Club--Claremont	SCAQMD	(3) 86 bhp rich-burn engine cogeneration system	3-way catalyst: Miratech MN-11T-04F and air/fuel ratio controller	10/00	engine #1	0.112 gm/bhp-hr	0.035 gm/bhp-hr	0.091gm/bhp-hr
					engine #2	0.003 gm/bhp-hr	0.044 gm/bhp-hr	0.142 gm/bhp-hr
					engine #3	0.005 gm/bhp-hr	0.026 gm/bhp-hr	0.075 gm/bhp-hr
College of the Desert--Palm Desert	SCAQMD	161 bhp Tecochill/Tecogen 74000LE rich-burn engine driving a compressor	3-way catalyst and air/fuel ratio controller	1/99	NA	0.044 gm/bhp-hr or 7 ppmvd	0.085 gm/bhp-hr or 38 ppmvd	0.255 gm/bhp-hr or 64 ppmvd
Crestline Village Water District--Crestline	SCAQMD	94 bhp Ford LSG875 rich-burn engine driving a generator	3-way catalyst: Miratech MN-09-04F-D2 and air/fuel ratio controller	7/00	NA	<0.15 gm/bhp-hr or <20 ppmvd	0.02 gm/bhp-hr or 3 ppmvd	0.34 gm/bhp-hr or 31 ppmvd
Gill's Onions--Oxnard	Ventura Co. APCD	158 bhp Tecodrive 7400LE rich-burn engine driving refrigeration compressor and 250 bhp Waukesha F11 GSID driving air compressor	3-way catalyst and air/fuel ratio controller	1/00	Tecodrive #1	7	5.8	55
					Waukesha	5	1.4	10
Gill's Onions--Oxnard	Ventura Co. APCD	(2) 158 bhp Tecodrive 7400LE rich-burn engine driving a refrigeration compressor and 815 bhp Caterpillar G3512 rich-burn engine driving an air compressor	3-way catalyst and air/fuel ratio controller	11/00	Tecodrive #2	2	<0.5	30
					Tecodrive #3	8	<0.5	58
					Caterpillar	4.5	2.1	50

Table B-4
Emission Source Test Results for Engines Using Fossil Fuel

Facility Name	District / State	Description of Basic Equipment	Method of control	Date tested	Engine or test #	Measured Concentrations (ppmvd @ 15%O2)*		
						NOX	VOC	CO
Gill's Onions--Oxnard	Ventura Co. APCD	158 bhp Tecodrive 7400LE rich-burn engine driving refrigeration a compressor and 250 bhp Waukesha F11 GSID rich-burn engine driving an air compressor	3-way catalyst and air/fuel ratio controller	2/01	Tecodrive #1	0.8	<0.5	12
					Waukesha	6.3	<0.5	6
Los Alamos Energy	Santa Barbara Co. APCD	(2) 713 bhp field gas-fired Caterpillar G398TAHC rich-burn engine driving a generator producing a total of 0.93 MW	3-way catalyst and air/fuel ratio controller	1997	engine #1	3.6	0.14	165
				1998	engine #1	65**	NA***	NA
				1999	engine #1	13	NA	NA
				1999	engine #1	11	NA	NA
				2000	engine #1	3	NA	NA
				1997	engine #2	0.6	0.16	87
				1998	engine #2	4	0.8	714
				1999	engine #2	5	NA	NA
				2000	engine #2	11	NA	NA

Table B-4
Emission Source Test Results for Engines Using Fossil Fuel

Facility Name	District / State	Description of Basic Equipment	Method of control	Date tested	Engine or test #	Measured Concentrations (ppmvd @ 15%O_2)*		
						NOX	VOC	CO
Los Angeles County, Metropolitan Transit Authority--Los Angeles	SCAQMD	400 bhp Caterpillar G3408TA HCR rich-burn engine driving a compressor	3-way catalyst: Johnson Mathey QXH50-8 and air/fuel ratio controller	9/99	NA	0.01gm/bhp-hr or <2 ppmvd	0.03 gm/bhp-hr or 7 ppmvd	0.12 gm/bhp-hr or 15 ppmvd
Saba Petroleum	Santa Barbara Co. APCD	747 bhp Waukesha 3521GSI rich-burn engine driving a compressor	3-way catalyst and air/fuel ratio controller	1999	NA	0.14 gm/bhp-hr	0.04 gm/bhp-hr	0.36 gm/bhp-hr
				2000	NA	0.065 gm/bhp-hr	0.01 gm/bhp-hr	0.13 gm/bhp-hr
SB Linden--Linden, NJ	NJDEP	3,130 bhp Waukesha 12VAT27GL lean-burn engine driving a pump	SCR and oxidation catalyst	1997	test #1	16.5	NA	26.5
					test #2	13.9	NA	25.8
					test #3	14	NA	25.1
					test #4	15.6	NA	24.8
Trillium USA--Los Angeles	SCAQMD	(3) 607 bhp Caterpillar G3412TAA rich-burn engine driving a compressor	3-way catalyst: Miratech EQ-700-XX-D2 and tecodrive air/fuel ratio controller	11/00	Unit A	0.024 gm/bhp-hr	0.008 gm/bhp-hr	0.016 gm/bhp-hr
					Unit B	0.009 gm/bhp-hr	0.004 gm/bhp-hr	0.15 gm/bhp-hr
					Unit C	0.06 gm/bhp-hr	0.004 gm/bhp-hr	0.31 gm/bhp-hr

Table B-4
Emission Source Test Results for Engines Using Fossil Fuel

Facility Name	District / State	Description of Basic Equipment	Method of control	Date tested	Engine or test #	Measured Concentrations (ppmvd @ 15%O2)*		
						NOX	VOC	CO
Trillium USA--West Hollywood	SCAQMD	(3) 607 bhp Caterpillar G3412TAA rich-burn engine driving a compressor	3-way catalyst: Miratech EQ-700-XX-D2 and tecodrive air/fuel ratio controller	8/00	Unit A	0.1 gm/bhp-hr	0.007 gm/bhp-hr	0.34 gm/bhp-hr
					Unit B	0.1 gm/bhp-hr	0.01 gm/bhp-hr	0.4 gm/bhp-hr
Tosco-Ventura Pump Station--Ventura	Ventura Co. APCD	415 bhp Caterpillar SP321P001-G379ASI rich-burn engine driving a pump	3-way catalyst and air/fuel ratio controller	ARB test 3/01	NA	1.2	58.4****	245
				1/01	NA	3.4	6	180
Vintage Petroleum--Piru	Ventura Co. APCD	325 bhp Caterpillar 3406TD rich-burn engine driving a pump	3-way catalyst and air/fuel ratio controller	9/99	NA	7	76	381

* unless otherwise indicated

** original test did not meet district standard. After modifications, engine was retested.

*** test for CO and VOC taken in lb/day--no data available in ppm

**** total hydrocarbons

Additionally, the NOx concentrations with a new catalyst are typically well below the 9 ppmvd BACT level--in some cases, initial tests have shown results below 2 ppmvd at 15 percent O_2. Fourteen of the 21 initial compliance test were below 5 ppmvd at 15 percent O_2 for NOx and of the 32 total tests shown in Table B-4, 20 of the test results were below 5 ppmvd at 15 percent O_2.

The experience gained in using a three-way catalyst in thousands of applications has identified the pitfalls to be avoided in order to ensure the optimum effectiveness and life of the control system. For example, initial catalyst masking problems were solved by using an ash-free lube oil. Catalytic converter manufacturers now require limits on certain chemical poisons in both the lube oil and the fuel used in the engine. Temperature of the fuel gas also plays a role in that optimum efficiency occurs within a certain temperature window and that the excessive heat for the catalytic converter can also adversely affect the life and overall emission reduction of the unit. Additionally, certain applications involving significant idle conditions could result in reduced overall efficiency of the catalyst due to not maintaining the proper temperature requirements. Modifying the operation of the engine by reducing the idling time solved this issue.

For lean-burn engines, there is only one emission test result available. The results of the compliance test for the SB Linden, New Jersey engine indicates the measured NOx levels are well below the NOx permit limit of 50 ppmvd at 15 percent O_2, averaging about 15 ppmvd at 15 percent O_2--about 70 percent lower than the original permit limit. The NEO California Power LLC power plant located in Chowchilla, composed of 16 large lean-burn engines equipped with SCR and oxidation catalyst initiated operation in early June 2001. Similarly, the NEO California Power LLC Red Bluff facility initiated operation in August 2001. Source test results for both facilities should be available later in 2001.

E. More Stringent Control Techniques

1. Technologically Feasible Controls

a. NoxTech

The technology is relatively new and has only been applied commercially to diesel engine generators with great success--achieving over 90 percent reduction in NOx emissions over a two year period. A description of the technology is given in Appendix B of the draft ARB report: Reasonably Available Control Technology and Best Available Retrofit Control Technology for Stationary Spark-Ignited Internal Combustion Engines, April 2000. This report is scheduled to be finalized later this year.

This control method should be effective on lean-burn engines, subject to the limits discussed below. The major concern is the cost effectiveness of NOxTech. Because of the high energy needs for the technology (the fuel penalty can be as high as 10 percent), the operating cost associated with using NoxTech is higher than with SCR. Consequently, this technology may not be cost effective for engines that do not operate at a high operating capacity. Additionally, NoxTech may not be suitable for engines that do not operate with a relatively constant load.

2. Developing Control Technologies

a. SCONOX

As discussed above, the focus of the SCONOX technology has only been used for reducing NOx emissions from gas turbines. EmeraChem is now adapting the SCONOX technology to reduce NOx emissions from engines. For example, SCONOX was installed on two large natural gas-fueled engine generators at Texas Instruments. However, the facility subsequently closed prior to the commercial operation of the two engines. In addition, EmeraChem is working with Cummins to adapt the SCONOX technology to diesel engines.

In summary, it appears that SCONOX technology could be applied to lean-burn or rich-burn engines. However, the technology has not been used to control the emissions from an engine outside of a laboratory setting. In the application of the technology on gas turbines, there have been technical issues at each of its installations regarding the initial implementation of the technology. Consequently, commercial demonstrations are needed to dispel these concerns. In addition, it is unclear what the overall cost effectiveness of the SCONOX technology is relative to other control techniques used for engines.

b. Lean NOx Catalyst

This technology is being developed to reduce emissions from diesel engines used in on-highway applications. This control method is still in the developmental stage and is not expected to be commercially available until the end of the decade. The efficiency for the technology, based upon laboratory tests, for reducing NOx emissions ranges from 25-50 percent, which is considerably less than the levels achieved by either SCR or SCONOx. The Manufacturers of Emission Controls Association (MECA) report Emission Control Technology for Stationary Internal Combustion Engines, 1997 indicated that in a test on a stationary engine, reductions of 80 percent were achieved.

F. Discussion and Recommendation

The most stringent emission limit for a reciprocating engine was required in the preconstruction permits for NEO California Power LLC (for two locations: Chowchilla and Red Bluff), JST Energy LLC located at Red Bluff, and Aera Energy for engines located in the oil fields of San Joaquin Valley. The determination for NEO California Power and JST Energy was made for lean-burn engines (4,157 bhp Deutz model TBG632V16 and 3,928 bhp Wartsila model 18V220SG) equipped with SCR and oxidation catalyst. Emission limits were specified at 0.07 g/bhp-hr for NOx, 0.15 g/bhp-hr for VOC, and 0.6 g/bhp-hr for CO. The other determination for Area Energy was for a rich-burn engine (either an 800 bhp Superior 8G-825 engine or a 1,478 bhp Waukesha 7042 GSI engine) equipped with a three-way catalyst. Emission limits were specified at 0.071 g/bhp-hr for NOx, 0.069 g/bhp-hr for VOC, and 0.6 g/bhp-hr for CO.

The lowest emissions achieved in practice for a lean-burn engine are for the 2,113 bhp Waukesha model 8LAT27GL engine located at the SB Linden facility located in New Jersey. The BACT determination limited emissions of the engine to 50 ppmvd at 15 percent O_2 for NOx, 58 ppmvd at 15 percent O_2 for VOC, and 76 ppmvd at 15 percent O_2 for CO. The engine has been in operation since 1997 and emission tests conducted in 1997 indicated NOx emissions were well below the limit in the preconstruction permit. The measurements were 17 ppmvd at 15 percent O_2 or less, and CO emissions was also well below the limit in the preconstruction permit, measuring in all cases below 27 ppmvd at 15 percent O_2. The equivalent g/bhp-hr is 0.2 for both NOx and CO. VOC emission was measured with a test method not consistent with methods used in California and therefore, is not included in this analysis.

The most stringent BACT levels achieved in practice for a rich-burn engine are the emission levels currently specified as BACT in the SCAQMD--these levels are applicable to all nonemergency reciprocating engines. These emission levels are 0.15 g/bhp-hr (9 ppmvd at 15 percent O_2) for NOx, 0.15 g/bhp-hr (25 ppmvd at 15 percent O_2) for VOC, and 0.6 g/bhp-hr (56 ppmvd at 15 percent O_2) for CO. These emission standards have represented BACT since 1998. In addition, engines varying in size from 86 bhp to 747 bhp engines have been equipped with three-way catalyst to satisfy these emission standards.

For rich-burn engines, as discussed above, in satisfying a BACT level of 9 ppmvd at 15 percent O_2 or 0.15 g/bhp-hr, 60 percent of all engines with test data achieved a 5 ppmvd at 15 percent O_2 or 0.07 g/bhp-hr emission level for NOx or better. Additionally, 65 percent of the engines achieved this level for NOx in the initial compliance test. This level has been achieved for a wide range of engine horsepower sizes: from about 80 hp up to about 750 hp. In addition, one engine at Los Alamos Energy has operated with three-way catalyst since 1997 and over this period, has been below 5 ppmvd at 15 percent O_2 for three years.

The control technologies identified to attain the most stringent level contained in a preconstruction permit are the same control technologies used to reach the lowest level achieved in practice. The ARB staff believes the BACT levels of 0.07 g/bhp-hr for NOx, 0.15 g/bhp-hr for VOC, and 0.6 g/bhp-hr for CO are technically achievable. To attain these levels, additional amounts of catalysts will be required, and in the case of SCR, additional amounts of ammonia/urea may need to be used.

Based upon the above, the ARB staff recommends establishing a BACT level based upon the achieved in practice levels of the SCAQMD requirements for nonemergency engines. As discussed above, the staff believes the 0.07 g/bhp-hr level proposed in the permits for Aera Energy and for NEO California Power is technically achievable. Consequently, district permitting staffs are encouraged to evaluate these BACT levels represented by these projects as part of the technical feasibility portion of the case-by-case BACT determination for power generating projects. In addition, once the NEO California Power has demonstrated achievement of the 0.07 g/bhp-hr NOx level, the ARB staff will consider this level to be achieved in practice for its class and category. Finally, an emission limit for PM was added. This PM level is consistent with the technology requirements of the ARB report entitled Risk Management Guidance for the Permitting of New Stationary Diesel-Fueled Engines, October 2000.

IV. INTERNAL COMBUSTION ENGINES OR GAS TURBINES USING WASTE GASES

Both reciprocating engines and gas turbines have been used to recover energy at landfills and wastewater treatment facilities. At landfills, to ensure the removal of toxic emissions, landfill gas is usually flared. From an energy perspective, no energy benefit is realized if the gas is flared. Consequently, the combustion of landfill gas in either engines or gas turbines to recovery energy from landfill gas that would otherwise be flared is beneficial from both an energy perspective and in reduction of green house gases. Digesters at wastewater treatment facilities are an ideal combined heat and power application in that the engine can produce both heat and electricity--the heat is needed in the digestion process and the electricity can be used to power equipment at the facility.

A. Control Technologies

Both landfill and digester gas contains impurities that, if combusted will likely poison post-combustion control systems that are based upon catalysts. Consequently, the approach for combusting waste gas in either a reciprocating engine or gas turbine has centered on either combustion processes that result in minimal NOx being produced such as low NOx burners for gas turbines and noncatalytic control systems such as steam/water injection for a gas turbine. For reciprocating engines, lean-burn engines have been the choice because these types of engines produce the lowest emission of NOx without using post combustion treatment technologies. In the case of gas turbines, the control techniques used in these applications include either low NOx combustors or water/steam injection to reduce NOx emissions.

B. Current SIP Control Measures

While there are no specific SIP control measures specifying reductions from waste gas combustion, many SIP measures affecting reciprocating engines have provisions affecting engines used in waste gas applications or have emission limits for lean-burn engines. The most stringent SIP measures have been adopted by SCAQMD, AVAPCD, and SDCAPCD. Both measures set emission standards for NOx, VOC, and CO. The SCAQMD and AVAPCD require reciprocating engines using waste gas to meet the following emission standards: 50-63 ppm at 15 percent O_2 for NOx, 350-440 ppm at 15 percent O_2 for VOC, and 2000 ppm at 15 percent O_2 for CO, with the applicable NOx and VOC standard depending upon the efficiency of the engine. SDCAPCD does not regulate waste gas usage, but requires lean-burn engines to achieve either 65 ppm at 15 percent O_2 or 90 percent reduction for NOx.

For gas turbines, the most stringent of these measures has been adopted by SCAQMD and AVAPCD. For the turbines typically used in landfill applications, these measures limit the NOx emissions from 9 to 25 ppmvd at 15 percent O2, based upon the size and efficiency of the turbine. In addition, a limit of 25 ppmvd applies to turbines rated between 2.9 and 10 MW which use a fuel with a minimum percentage of 60 percent sewage digester gas.

C. Control Techniques Required as BACT

1. BACT Guidelines

Of the districts with published BACT guidelines, the most stringent requirements for reciprocating engines or gas turbines fueled with either landfill or digester gas have been proposed by SCAQMD. For all stationary reciprocating engines using either landfill gas or digester gas, the levels are set at 0.6 g/bhp-hr for NOx, 0.6 g/bhp-hr for VOC, and 2.5 g/hp-hr for CO. Similarly, for gas turbines using either landfill gas or digester gas, the levels are set at 25 ppmvd at 15 percent O_2 for NOx and 130 ppmvd at 15 percent O_2 for CO.

2. BACT Determinations

Tables B-5 and B-6 list the most stringent emission limits required by California districts in preconstruction permits, for emissions of NOx, VOC, CO, for

Table B-5
Emission Control Requirements for Engines And Gas Turbines Using Landfill Gas

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Limit (g/bhp-hr)*			
				Permit Status	NOX	VOC	CO
County of Sacramento--Kiefer Landfill	Sacramento Metropolitan AQMD	(3) 4,230 bhp Caterpillar G3616 lean-burn engine driving a 3 MW electric generator	Lean-burn technology	ATC 8/98	0.55	NA	2.7
Energy Developments Inc--Azusa Landfill	SCAQMD	(5) 1,850 bhp Deutz TBG620 v16k lean-burn engine driving a generator	Lean-burn technology	PTC 5/00	0.6	0.17	2
Minnesota Methane Tajiguas Corporation-- Tajiguas Landfill	Santa Barbara Co. APCD	4,314 bhp Caterpillar 3616 lean-burn engine driving a 3 MW electric generator	Lean-burn technology	ATC 1/98	0.59	0.24	2.5
Riverside County Waste Management--Badlands	SCAQMD	1,777 bhp Deutz TBG620 v16k lean-burn engine driving a generator	Lean-burn technology	PTC 11/98	0.31	0.02	1.49
University of California at Los Angeles--Los Angeles	SCAQMD	(2) General Electric LM1600 generating 14.4 MW (140 MMBtu/hr) with heat recovery steam generator and steam turbine for total of 48 MW	Water injection and SCR	PTO 1995	6 ppmvd	NA	10 ppmvd

* unless otherwise indicated; ppmvd expressed at 15% O2.

Table B-6
Emission Control Requirements for Engines or Turbines Using Digester Gas

Facility Name	District / State	Description of Basic Equipment	Method of control	Permit Status	Permit Limit (g/bhp-hr)*		
					NOX	VOC	CO
City of Stockton	SJVUAPCD	(3) 1,408 bhp Waukesha L7042GLD digester/natural gas lean-burn engine generating 1.05 MW each for a total of 3.15 MW; cogeneration: electricity used onsite and hot water generated for digester	Lean-burn technology	ATC 10/99	1.25	0.75	2.65
Hemet/San Jacinto Regional Water Reclamation Facility--San Jacinto	SCAQMD	260 bhp Caterpillar G379 SI-TA-HCR spark ignition digester gas-fired, with pre-stratified charge system driving a aeration blower	Pre-stratified charge system	ATC 2/99	0.6	0.8	2.5
Joint Water Pollution Control Plant--Carson	SCAQMD	(3) Solar Mars 90 generating 9.9 MW (113 MMBtu/hr) with heat recovery steam generator and one 5.1 MW steam turbine for total of 34.8 MW	Water injection	ATC 7/00	25 ppmvd	NA	NA

* unless otherwise indicated; ppmvd expressed at 15% O2.

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engines used in landfill gas applications and engines or turbines used in digester gas applications respectively. For engines used in landfill applications, examples of district BACT determinations are for engines ranging from about 850 hp up to over 4,000 hp. Similarly, examples of BACT determinations for digester gas fired engines include two reciprocating engines (260 hp and 1,400 hp) and a gas turbine.

For engines combusting either landfill or digester gas, the recent permit limits have required lean-burn engines to achieve NOx levels of 0.55-0.6 g/bhp-hr (40-45 ppmvd at 15 percent O_2). There was one district determination specifying a NOx emission limit as 0.31 g/bhp-hr (See Riverside County Waste Management--Badlands), based upon an applicant's proposal, which is considerably lower than the other emission limits listed in Table B-5. This level is based upon a vendor guarantee.

There has been a wider range of emission levels established for the other pollutants. VOC BACT emission levels have been specified at 0.75 -0.8 (160-170 ppmvd at 15 percent O_2) when using digester gas and 0.25 g/bhp-hr or less (50 ppmvd at 15 percent O_2) when using landfill gas. For CO emission levels, the standard is not fuel specific and varies between 2 and 2.7 g/bhp-hr (250-330 ppmvd at 15 percent O_2).

For gas turbines, the most stringent emission level that has appeared in a preconstruction permit for use of either landfill or digester gas is for Joint Water Pollution Control Plant in Carson. The permit established limit of 25 ppmvd at 15 percent O2 for NOx emissions. The determination is for three Solar Mars 90 (10 MW) combined cycle plant generating a total of 34.8 MW. The level is achieved with water injection. In addition, the BACT determination for the gas turbine at UCLA is not applicable because the turbines at UCLA burn a mixture of landfill gas and natural gas with the majority of the fuel being natural gas.

D. Emission Levels Achieved in Practice

Tables B-7 and B-8 list the most stringent emission levels achieved, based upon emission testing, for NOx, VOC, and CO, for engines used in landfill gas applications and engines or turbines used in digester gas applications respectively. For the engines used in landfill applications, the engines tested range from 850 hp to 4,300 hp. Similarly, for digester gas fueled engines, the tested engines range from 260 hp to 1,400 hp. Some of these engines were listed in the previous section.

In general, the examples listed demonstrate compliance with the district BACT determination for NOx of 0.6 g/bhp-hr. For landfill gas fueled engines, the results of the testing varied from 0.31 to 0.48 g/bhp-hr of NOx, which demonstrates the variability of the landfill gas composition on the engine's NOx emissions. Similar results were seen for engines using digester gas in that results of the testing varied from 0.36 to 0.52 g/bhp-hr of NOx. Note that the tests for the engines at the City of

Table B-7
Emission Source Test Results for Engines Using Landfill Gas

Facility Name	District / State	Description of Basic Equipment	Method of control	Date Tested	Engine tested	Measured (g/bhp-hr)*		
						NOX	VOC	CO
County of Sacramento--Kiefer Landfill	Sacramento Metropolitan AQMD	(3) 4,230 bhp Caterpillar G3616 lean-burn engine driving a 3 MW electric generator for a total of 9 MW	Lean-burn technology	1/00	#1	0.39 or 28 ppmvd	<0.15 or <50 ppmvd	1.73 or 209 ppmvd
					#2	0.41 or 31 ppmvd	<0.13 or <50 ppmvd	1.7 or 214 ppmvd
					#3	0.48 or 33 ppmvd	<0.15 or <50 ppmvd	1.9 or 213 ppmvd
Minnesota Methane --Lopez Landfill	SCAQMD	(2) 4,235 bhp Caterpillar G3616 lean-burn engine driving a 3.05 MW electric generator	Lean-burn technology	3/99	#1	0.41 or 27 ppmvd	0.05 or 9 ppmvd	1.73 or 189 ppmvd
					#2	0.56 or 35 ppmvd	0.09 or16 ppmvd	1.92 or 200 ppmvd
Minnesota Methane Tajiguas Corporation--Tajiguas Landfill	Santa Barbara Co. APCD	4,314 bhp Caterpillar 3616 lean-burn engine driving a 3 MW electric generator	Lean-burn technology	1/01	85-100 load	0.31 or 24 ppmvd	0.1 or 6 ppmvd	1.59 or 211 ppmvd
					75% load	0.27 or 20 ppmvd	0.22 or 14 ppmvd	1.8 or 213 ppmvd
					62% load	0.2 or 15 ppmvd	0.27 or 17 ppmvd	1.8 or 212 ppmvd
Minnesota Methane--Corona	SCAQMD	850 bhp Caterpillar G399TA lean-burn engine driving a generator	Lean-burn technology	1997	NA	0.6	0.2	1.5
Ogden Power Pacific--Stockton	SJVUAPCD	1,100 bhp Cooper 8GTLA lean-burn engine driving a generator	Lean-burn technology	12/00	NA	0.45 or 28 ppmvd	0.32 or 58 ppmvd	3.9 or 399 ppmvd

* unless otherwise indicated; ppmvd expressed at 15% O2

Table B-8
Emission Source Test Results for Engines or Turbines Using Digester Gas

Facility Name	District / State	Description of Basic Equipment	Method of control	Date tested	Engine tested	Measured (g/bhp-hr)*		
						NOX	VOC	CO
City of Stockton	SJVUAPCD	(3) 1,408 bhp Waukesha L7042GLD digester/natural gas lean-burn engine generating 1.05 MW each for a total of 3.15 MW; cogeneration: electricity used onsite and hot water generated for digester	Lean-burn technology	10/00 digester gas	#3	0.52 or 30 ppmvd	<0.16 or <26 ppmvd	2.6 or 243 ppmvd
				10/00 digester gas	#4	0.45 or 26 ppmvd	<0.16 or <25 ppmvd	2.5 or 233 ppmvd
				10/00 digester gas	#1	0.49 or 31 ppmvd	<0.14 or <25 ppmvd	2.4 or 245 ppmvd
				10/00 NG	#3	0.58 or 36 ppmvd	<0.16 or <27 ppmvd	2.5 or 255 ppmvd
				10/00 NG	#4	0.47 or 29 ppmvd	<0.155 or <27 ppmvd	2.5 or 250 ppmvd
				10/00 NG	#1	0.54 or 35 ppmvd	<0.14 or <27 ppmvd	2.5 or 266 ppmvd
Hemet/San Jacinto Regional Water Reclamation Facility--San Jacinto	SCAQMD	260 bhp Caterpillar G379 SI-TA-HCR spark ignition digester gas-fired engine, with pre-stratified charge system driving a aeration blower	Pre-stratified charge system	5/00	NA	0.487 or 32 ppmvd	0.539 or 101 ppmvd	1.524 or 163 ppmvd

Table B-8
Emission Source Test Results for Engines or Turbines Using Digester Gas

Facility Name	District / State	Description of Basic Equipment	Method of control	Date tested	Engine tested	Measured (g/bhp-hr)* NOX	VOC	CO
Joint Water Pollution Control Plant--Carson	SCAQMD	(3) Solar Mars 90 turbines generating 9.9 MW (113 MMBtu/hr) with heat recovery steam generator and one 5.1 MW steam turbine for total of 34.8 MW	Water injection / SCR	12/99	Turbine #1	19.3 ppmvd	NA	12 ppmvd
					Turbine #2	21.5 ppmvd	NA	8 ppmvd
					Turbine #3	21.2 ppmvd	NA	19 ppmvd
Orange County Sanitation District--Huntington Beach	SCAQMD	4,166 bhp Cooper LSVB-16-SGC lean burn engine driving a 3 MW generator with heat recovery steam generator	Lean burn technology	6/96	NA	0.36	0.2	2
South East Regional Reclamation Authority--Dana Point	SCAQMD	636 bhp Waukesha 2895GL, lean burn digester gas/natural gas-fired engine driving blower with heat recovery to digester tanks	Lean burn technology	6/96	NA	0.36	0.2	2

* unless otherwise indicated; ppmvd expressed at 15% O2.

Stockton indicates that emissions of NOx are higher with natural gas than with digester gas--probably resulting from the lower Btu content of the digester gas. In addition, the engines at the City of Stockton were well under the BACT determination of 1.25 g/bhp-hr.

For the other pollutants, there has been similar variation in emission levels. Some of this variation can be explained by operators striving to meet stringent NOx levels which can adversely affect CO or VOC emissions. For landfill gas fueled engines, VOC emission levels have varied from 0.05 to 0.32 g/bhp-hr, and for digester gas, VOC emission levels have varied from 0.2 to 0.5 g/bhp-hr. Similarly, for CO emission levels, the emission levels have varied from 1.6 to 3.9 g/bhp-hr for landfill gas and, the emission levels have varied from 1.5 to 2 g/bhp-hr for digester gas.

For gas turbines using a waste gas, Joint Water Pollution Control Plant, mentioned above, achieved between 19 and 22 ppmvd at 15 percent O_2 for NOx levels and 8 to 19 ppmvd at 15 percent O_2 for CO levels.

E. Discussion and Recommendation

A review of the BACT levels contained in district preconstruction permits and the emissions achieved in practice support a BACT level of 0.6 g/bhp-hr for NOx emissions from reciprocating engines combusting landfill or digester gas.

The most stringent level specified in a preconstruction permit for NOx is 0.31 g/bhp-hr. This determination is for a Deutz TBG620 lean burn engine at the Badlands Landfill in Riverside. The determination is based upon a vendor guarantee. However, as discussed above, this determination is much lower than other determinations for the same type of source. All the other recent determinations contained in the preconstruction permits range from 0.55 to 0.6 g/bhp-hr, except for a determination for Waukesha engines in Stockton. These engines were permitted at 1.25 g/bhp-hr--the previous BACT level, but as discussed below, the emissions achieved in practice were much lower.

As discussed above, the NOx emissions achieved in practice ranged from 0.31 to 0.52 g/bhp-hr for either landfill or digester gas. The most stringent BACT level achieved in practice for a reciprocating engines using waste gas is 0.31 g/bhp-hr for NOx, 0.1 g/bhp-hr for VOC, and 1.59 g/bhp-hr for CO. This determination is for a Caterpillar G3616 lean-burn engine at the Tajiguas Landfill in Santa Barbara. NOx emissions for the same engine at other landfills varied from 0.39 to 0.56 g/bhp-hr, indicating the influence of the quality of the landfill gas on NOx emissions. For the Waukesha engines in Stockton, the engines were tested at 0.45-0.52 g/bhp-hr for digester gas only--some 60 percent lower than the limit contained in the permit.

For gas turbines, the most stringent BACT determination for use of a waste gas that has appeared in a preconstruction permit is for the Joint Water Pollution Control Plant in Carson. The permit established a limit of 25 ppmvd at 15 percent O_2 for NOx emissions for each of the three Solar Mars 90 turbines. Subsequent testing indicated this level is achieved in practice.

Based on the above, the ARB staff recommends the following levels for a reciprocating engine using a waste gas: 0.6 g/bhp-hr for NOx, 0.6 g/bhp-hr for VOC, and 2.5 g/bhp-hr for CO. These levels are consistent with the SCAQMD's BACT guidance for this category of source. In addition, the VOC and CO are set at higher levels to allow operators the flexibility in combustion modifications to meet stringent NOx levels. For gas turbines using a waste gas, the ARB staff recommends that the BACT level be 25 ppmvd at 15 percent O_2 for NOx emissions.