ACTIVE

CATEGORY Type: **IC ENGINE SPARK - PRIME**

BACT Category: Minor Source BACT

| **BACT Determination Number:** | 363 | **BACT Determination Date:** | **7/16/2024** |
|---|---|---|---|

## Equipment Information

**Permit Number:** 27782

**Equipment Description:** DIGESTER GAS - ENGINE/GENERATOR - PRIME POWER

**Unit Size/Rating/Capacity:** 3,681 HP

**Equipment Location:**

8521 LAGUNA STATION RD ELK GROVE, CA

## BACT Determination Information

**District Contact:** Joanne Chan Phone No.: 279-207-1173 email: Jchan@airquality.org

| | | |
|---|---|---|
| **ROCs** | **Standard:** | 30 ppmvd @ 15% oxygen (0.10 g/hp-hr) |
| | **Technology Description:** | Biogas fuel pre-treatment system with an oxidation catalyst. |
| | **Basis:** | Achieved in Practice |
| **NOx** | **Standard:** | 11 ppmvd @ 15% oxygen (0.10 g/hp-hr) |
| | **Technology Description:** | Biogas fuel pre-treatment system with Selective Catalytic Reduction (or equivalent technology) and an oxidation catalyst. |
| | **Basis:** | Achieved in Practice |
| **SOx** | **Standard:** | Sulfur content of fuel (calculated as H2S): 40 ppmvd daily average, or see comments below. |
| | **Technology Description:** | Biogas fuel pre-treatment system. |
| | **Basis:** | Achieved in Practice |
| **PM10** | **Standard:** | 0.07 g/hp-hr |
| | **Technology Description:** | Biogas fuel pre-treatment system. |
| | **Basis:** | Achieved in Practice |
| **PM2.5** | **Standard:** | 0.07 g/hp-hr |
| | **Technology Description:** | Biogas fuel pre-treatment system. |
| | **Basis:** | Achieved in Practice |
| **CO** | **Standard:** | 250 ppmvd @ 15% oxygen (1.41 g/hp-hr) |
| | **Technology Description:** | Biogas fuel pre-treatment system with an oxidation catalyst. |
| | **Basis:** | Achieved in Practice |
| **LEAD** | **Standard:** | |
| | **Technology Description:** | |
| | **Basis:** | |

**Comments:** SOx : as shown above, or 40 ppmvd monthly average AND 500 ppmvd 15-minute average.
T-BACT : Oxidation catalyst achieving ≥ 50% reduction of formaldehyde emissions.

This is a project-specific BACT determination for the Sacramento Area Sewer District’s permit applications # 27782 - 27785. The term “digester gas“ for this BACT is defined as biogas produced from wastewater treatment facilities.

# BEST AVAILABLE CONTROL TECHNOLOGY (BACT) DETERMINATION

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|---|---|
| **DETERMINATION NO.:** | 363 |
| **DATE:** | January 30, 2024 |
| **ENGINEER:** | Joanne Chan / Felix Trujillo, Jr. |

| | |
|---|---|
| **Category/General Equip Description:** | Internal Combustion (I.C.) Engines |
| **BACT Category:** | Minor Source BACT |
| **Equipment Specific Description:** | I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled |
| **Equipment Size/Rating:** | 3,681 HP |
| **Previous BACT Determination No.:** | None |

## INTRODUCTION

This is a project-specific BACT determination (No. 363) for the Sacramento Area Sewer District's (SacSewer) I.C. prime power, spark-ignited, lean-burn, turbocharged, 4-cycle engines fueled by digester gas or a blend of digester gas and natural gas, rated at 3,681 HP (2.7 KW), and operating at a non-major stationary source (aka minor source) within the jurisdiction of the Sacramento Metropolitan Air Quality Management District (SMAQMD). SacSewer's project (permit application numbers 27782 – 27785) involves four (4) of these engines operating at their wastewater treatment facility at 8521 Laguna Station Road, Elk Grove, CA 95758. The SacSewer wastewater treatment facility is currently designated as a synthetic minor (SM80) source.

The term "digester gas" for this BACT determination is defined as biogas produced from wastewater treatment facilities. Digester gas is considered a biogas. Biogases include a broad category of gaseous renewable fuels produced from the anaerobic decomposition of raw materials such as agricultural waste, manure, plant material, food waste, sewage/wastewater, and municipal waste. Raw biogas consists of 50-75% methane ($CH_4$), 25-50% carbon dioxide ($CO_2$), and small amounts (2-8%) of nitrogen ($N_2$). Trace levels of hydrogen sulfide ($H_2S$), ammonia ($NH_3$), hydrogen ($H_2$), and various volatile organic compounds are also present in biogas depending on the feedstock.[1] Biogas from wastewater treatment facilities is produced from the anaerobic digestion of their sludge.

I.C. prime power, spark-ignited engines fueled by digester gas or a blend of digester gas and natural gas – use gaseous waste fuel to operate and provide primary electrical power to the facility and its operations. Lean burn engines are commonly used for high electrical efficiency and

[1] National Library of Medicine, National Center for Biotechnology Information, ***Composition and Toxicity of Biogas Produced from Different Feedstocks in California***, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7608650/#:~:text=Raw%20biogas%20typically%20consists%20of,biogas%20depending%20on%20the%20feedstock, accessed on January 30, 2024.

operation on biogases.[2] For wastewater treatment facilities, the engine would also provide heat to the digester(s).

As mentioned above, this BACT determination is for I.C. prime power, spark-ignited engines fueled by digester gas, or a blend of digester gas and natural gas. The composition of the fuel source is important for determining the types of air pollution controls (APC) that are necessary to reduce emissions.

- Commercial natural gas is composed of approximately 85-90% methane ($CH_4$), with the remainder mainly composed of ethane ($C_2H_6$) and nitrogen ($N_2$).[3] Pipeline natural gas in Sacramento County has a sulfur content of approximately 0.22 grains per 100 cubic feet and a higher heating value (HHV) of 1,000 Btu/scf.

- Silica compounds that could form siloxane are an issue if the biogas is produced from landfills or wastewater treatment facilities; therefore, the siloxanes must be removed from the biogas stream before the biogas enters the I.C. engine. Siloxanes come from human hygiene products, such as deodorants, antiperspirants, moisturizers, and sunscreens. Siloxanes will coat the catalyst and quickly diminish the effectiveness of the pollution control device. Other impurities in the raw biogas stream can also poison the catalyst.[4] Additionally, siloxanes can damage the I.C. engine by forming a hard deposit within it, which eventually causes equipment failure.[5]

- $SO_2$ emissions are controlled by removing hydrogen sulfide ($H_2S$) from the biogas stream before the conditioned biogas enters the I.C. engine. $H_2S$ will poison the catalyst used in the APC device; hence, it must be removed from the biogas stream prior to combustion in the engine.

- Even though digester gas-fueled engines of this size category are subject to SMAQMD's permitting requirements, the biogas fuel pre-treatment processes are exempt from these requirements since they do not produce criteria pollutant emissions.

This determination will also include Best Available Control Technology for Toxics (T-BACT) for the hazardous air pollutants (HAP) associated with digester gas fuel combustion.

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[2] Generac Corporation. Rich burn vs. Lean burn Natural Gas Engines Fact Sheet. https://www.generac.com/Industrial/GeneracCorporate/media/Library/email/Rich_burn_FactSheet.pdf, accessed on March 6, 2024.

[3] Composition and Properties of Natural Gas. https://www.britannica.com/science/natural-gas/Composition-and-properties-of-natural-gas, accessed on January 31, 2024.

[4] EPA RBLC ID: OR-0052, Permit # 11-0001-ST-02, Permit Date 6/21/2013, I.C. Engine for Electric Generator, Lean Burn, Fuel by Landfill Gas, Throughput = 2328 MMdscf/year. https://cfpub.epa.gov/rblc/index.cfm?action=PermitDetail.ProcessInfo&facility_id=28072&PROCESS_ID=110558, accessed on January 31, 2024.

[5] https://anaerobic-digestion.com/biogas-and-anaerobic-digestion/difference-biogas-landfill-gas/#:~:text=The%20difference%20is%20that%20landfill,found%20in%20any%20landfill%20gas, accessed on January 30, 2024.

**BACT / T-BACT ANALYSIS**

## A. ACHIEVED IN PRACTICE (Rule 202, §205.1a):

The following control technologies are currently employed as BACT/T-BACT for I.C. prime power, spark-ignited engines fueled by digester gas or a blend of digester gas and natural gas by the following agencies and Air Pollution Control Districts (APCD) / Air Quality Management Districts (AQMD).

Note: Tables 3.2-1, 3.2-2, and 3.2-3 of AP-42 list benzene, formaldehyde, PAHs, naphthalene, acetaldehyde, acrolein, propylene, toluene, xylenes, ethyl benzene, and hexane as the primary drivers for health risks associated with natural gas combustion. These HAPs/organic compounds are emitted as VOC, and the same control technologies that control VOCs also control the listed HAPs.

| United States Environmental Protection Agency (US EPA) |
|---|

**BACT**
Source: US EPA RACT/BACT/LAER Clearinghouse (See Attachment A)

US EPA's RACT/BACT/LAER[6] Clearinghouse (RBLC) search from 1/1/2013 to 1/30/2024, under process type 17.140 for Large Internal Combustion Engines (>500 HP) Fueled by Landfill/Digester/Biogas, yielded twelve (12) permits at landfill facilities. Eleven (11) of those permits were for landfill gas-fueled engines and one (1) was for a landfill or digester gas-fueled engine. The search yielded no results for digester gas-fueled engines at wastewater treatment facilities.

Although landfill gas is similar in composition to digester gas produced from wastewater treatment facilities, landfill gas can contain trace amounts of various volatile organic compounds. Landfill gas is composed of approximately 50% methane, 50% carbon dioxide ($CO_2$), and a small amount of non-methane organic compounds.[7] As mentioned above, this minor source BACT determination is focused on digester gas-fueled prime power engines; therefore, SMAQMD will not consider the permit standards for landfill gas-fueled engines in this evaluation. Additionally, the permit standards for the one (1) landfill or digester gas-fueled engine will not be considered in this evaluation because the standards were for engines operating at a major source.

Therefore, there are no standards for VOC, NOx, SOx, PM10, PM2.5, and CO from the EPA's RACT/BACT/LAER Clearinghouse that are applicable to this BACT determination.

[6] The terms RACT, BACT, and LAER are acronyms under the US EPA's New Source Review (NSR) program. Reasonably Available Control Technology (RACT) is required on existing sources in areas that do not meet national ambient air quality standards (non-attainment areas). Best Available Control Technology (BACT) is required on new/modified major sources in attainment areas. Lowest Achievable Emission Rate (LAER) is required on new/modified major sources in non-attainment areas. BACT, LAER, and sometimes RACT are determined on a case-by-case basis, usually by State or local permitting agencies. US EPA established the RACT/BACT/LAER Clearinghouse to provide a central air pollution technology information database.
https://www.epa.gov/catc/ractbactlaer-clearinghouse-rblc-basic-information, accessed on January 30, 2024.

[7] https://www.epa.gov/lmop/basic-information-about-landfill-gas, accessed on January 30, 2024.

***US EPA – continued***

| **I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled** | |
|---|---|
| **VOC** | N/A – No BACT determinations found. |
| **NOx** | N/A – No BACT determinations found. |
| **SOx** | N/A – No BACT determinations found. |
| **PM10** | N/A – No BACT determinations found. |
| **PM2.5** | N/A – No BACT determinations found. |
| **CO** | N/A – No BACT determinations found. |

**T-BACT**
There are no T-BACT standards published in the EPA's RACT/BACT/LAER Clearinghouse for this category.

**RULE REQUIREMENTS**

40 CFR Part 60 Subpart JJJJ – Standards of Performance for Stationary Spark Ignition Internal Combustion Engines: This regulation applies to owners/operators of new stationary spark-ignition engines that commenced construction after June 12, 2006, where the engines are manufactured:

- on or after July 1, 2007, for engines with a maximum engine power greater than or equal to 500 HP (except lean burn engines with a maximum engine power between 500 ≤ HP < 1,350). [40 CFR §60.4230(a)(4)(i)]

- on or after January 1, 2008, for lean burn engines with a maximum engine power between 500 ≤ HP < 1,350. [40 CFR §60.4230(a)(4)(ii)]

40 CFR §60.4248 defines "digester gas" as any gaseous by-product of wastewater treatment typically formed through the anaerobic decomposition of organic waste materials and composed principally of methane and carbon dioxide ($CO_2$).

Since this BACT determination is for I.C. prime power, spark-ignited engines fueled by digester gas or a blend of digester gas and natural gas, the applicable emission standards are shown below in the excerpt from Table 1 of 40 CFR Part 60 Subpart JJJJ. Table 1 of this subpart applies to lean burn and rich burn spark-ignited engines fueled by digester gas.

Except for gasoline and rich burn engines that use liquified petroleum gas (LPG), owners/operators of stationary spark-ignited I.C. engines with a maximum engine power greater than or equal to 100 HP (75 KW) must comply with the emission standards in Table 1 to this subpart for their engine [40 CFR §60.4233(e)].

***US EPA – continued***

**Excerpt from Table 1 of 40 CFR Part 60 Subpart JJJJ — $NO_X$, CO, and VOC Emission Standards for Stationary Spark-Ignited Landfill / Digester Gas Engines**

| Engine and Fuel Type | Maximum Engine HP | Manufacture Date | Emission Standards (A) (B) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | g/HP-hr | | | ppmvd @ 15% $O_2$ | | |
| | | | NOx | CO | VOC | NOx | CO | VOC |
| Landfill / Digester Gas (except lean burn 500 ≤ HP< 1,350) | HP < 500 | 7/01/2008 | 3.0 | 5.0 | 1.0 | 220 | 610 | 80 |
| | | 1/01/2011 | 2.0 | 5.0 | 1.0 | 150 | 610 | 80 |
| | HP ≥ 500 | 7/01/2007 | 3.0 | 5.0 | 1.0 | 220 | 610 | 80 |
| | | 7/01/2010 | 2.0 | 5.0 | 1.0 | 150 | 610 | 80 |
| Landfill / Digester Gas (lean burn) | 500 ≤ HP< 1,350 | 1/01/2008 | 3.0 | 5.0 | 1.0 | 220 | 610 | 80 |
| | | 7/01/2010 | 2.0 | 5.0 | 1.0 | 150 | 610 | 80 |

(A) Owners and operators of stationary non-certified SI engines may choose to comply with the emission standards in units of either g/HP-hr or ppmvd @ 15% $O_2$.

(B) For purposes of this subpart, formaldehyde emissions should not be included when calculating emissions of volatile organic compounds (VOC).

40 CFR Part 60 Subpart ZZZZ – National Emissions Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines: This regulation applies to owners/operators of stationary reciprocating internal combustion engines (RICE) located at both major and area sources of Hazardous Air Pollutant (HAP) emissions. [40 CFR §63.6585]

An affected source that meets any of the criteria in paragraphs (1) through (7) of this section must meet the requirements of this part by meeting the requirements of 40 CFR part 60 subpart IIII, for compression ignition engines or 40 CFR part 60 subpart JJJJ, for spark ignition engines. [40 CFR §63.6590(c)]

Since the I.C. prime power, spark-ignited, digester gas-fueled engines under this BACT determination must comply with 40 CFR part 60 subpart JJJJ, there are no further requirements under 40 CFR Part 60 Subpart ZZZZ that apply to this engine category.

## California Air Resources Board (CARB)

**BACT**

Source: CARB BACT Clearinghouse (See Attachment B)

As of April 10, 2024, the CARB BACT Clearinghouse has four (4) BACT determinations for I.C. prime power, spark-ignited engines fueled by digester gas or biogas. The BACT determinations applied only to major sources will not be considered in this minor source BACT evaluation.

The most stringent standards from the CARB BACT Clearinghouse are listed below.[8] Further details and updates to this BACT determination are shown in the Bay Area AQMD section of this evaluation.

| **I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled (A)** | |
|---|---|
| **VOC (B)** | Technology Feasible / Cost Effective: 0.12 g/bhp-hr<br>Achieved in Practice: 0.16 g/bhp-hr |
| **NOx (C)** | Technology Feasible / Cost Effective: No Standard<br>Achieved in Practice: 0.15 g/bhp-hr |
| **SOx** | Technology Feasible / Cost Effective: 100 ppmv of total sulfur in biogas<br>Achieved in Practice: 150 ppmv of total sulfur in biogas |
| **PM10** | Technology Feasible / Cost Effective: 0.07 g/bhp-hr<br>Achieved in Practice: 0.10 g/bhp-hr |
| **PM2.5** | No Standard |
| **CO** | Technology Feasible / Cost Effective: 0.89 g/bhp-hr<br>Achieved in Practice: 1.8 g/bhp-hr |

(A) These were the BACT standards listed on CARB's BACT Clearinghouse, but these are not the most current BAAQMD BACT standards for this equipment category. BAAQMD provided SMAQMD with an update to their BACT standards via email dated 5/30/2024 (see Attachment C). See the BAAQMD section of this evaluation for further details.

(B) BAAQMD uses the term "precursor organic compounds (POC)" rather than SMAQMD's preferred terminology of volatile organic compounds (VOC).

(C) For SCR systems, ammonia emissions (NH3) are limited to an exhaust concentration of 10 ppmvd @ 15% $O_2$.

**T-BACT**

Use of an oxidation catalyst achieving 50% or better control of formaldehyde emissions, which are a precursor organic compound and a toxic air contaminant.

[8] CARB BACT Clearinghouse. Bay Area Air Quality Management District BACT Guideline (Rev 1), Document # 96.2.4. Equipment Category: IC Engine - Biogas Fired, rated ≥ 50 HP (5/30/2013). https://ww2.arb.ca.gov/sites/default/files/classic/technology-clearinghouse/bact/BACTID1087.pdf?:linktarget=_self&:embed=yes, accessed on April 10, 2024.

***CARB – continued***

## RULE REQUIREMENTS

CARB does not have a statewide rule for control of stationary spark-ignited IC engines. However, when necessary, CARB develops guidelines that set Reasonable Available Control Technology (RACT) and Best Available Retrofit Control Technology (BARCT). These guidelines establish the minimum requirements for RACT and BARCT that Air Districts must consider when developing all feasible measures for attainment of the California Ambient Air Quality Standards.

CARB RACT/BARCT Guidelines for Stationary Spark-Ignited Internal Combustion Engines (11/2001): This document presents the determination of reasonably available control technology (RACT) and best available retrofit control technology (BARCT) for controlling NOx, VOC, and CO from stationary, spark-ignited reciprocating internal combustion engines. See Table II-1 and Table II-2 below. Page I-6 of this document lists landfills and sewage treatment facilities as sources of waste fuels, and page IV-8 lists sewage digester gas and landfill gas as examples of waste gas.

**Table II-1**

**Summary of RACT Standards for Stationary Spark-Ignited Internal Combustion Engines**

| Spark-Ignited Engine Type | % Control of NOx | Emission Standards (A) ppmv @ 15% $O_2$ | | |
|---|---|---|---|---|
| | | NOx | VOC | CO |
| **Rich-Burn** | | | | |
| Cyclically-loaded, Field Gas Fueled | -- | 300 | 250 | 4,500 |
| All Other Engines | 90 | 50 | 250 | 4,500 |
| **Lean-Burn** | | | | |
| Two Stroke, Gaseous Fueled, HP < 100 | -- | 200 | 750 | 4,500 |
| All Other Engines | 80 | 125 | 750 | 4,500 |

(A) For NOx, either the percent control or the parts per million by volume (ppmv) limit must be met by each engine where applicable. The percent control option applies only if a percentage is listed, and applies to engines using either combustion modification or exhaust controls. All engines must meet the ppmv VOC and CO limits.

***CARB – continued***

**Table II-2**

**Summary of BARCT Standards for Stationary Spark-Ignited Internal Combustion Engines**

| Spark-Ignited Engine Type | % Control of NOx | Emission Standards (A) ppmv @ 15% $O_2$ NOx | VOC | CO |
|---|---|---|---|---|
| **Rich-Burn** | | | | |
| Waste Gas Fueled | 90 | 50 | 250 | 4,500 |
| Cyclically-loaded, Field Gas Fueled | -- | 300 | 250 | 4,500 |
| All Other Engines | 96 | 25 | 250 | 4,500 |
| **Lean-Burn** | | | | |
| Two Stroke, Gaseous Fueled, HP < 100 | -- | 200 | 750 | 4,500 |
| All Other Engines | 90 | 65 | 750 | 4,500 |

(A) For NOx, either the percent control or the parts per million by volume (ppmv) limit must be met by each engine where applicable. The percent control option applies only if a percentage is listed, and applies to engines using either combustion modification or exhaust controls. All engines must meet the ppmv VOC and CO limits.

CARB Distributed Generation (DG) Certification Regulation (effective date 9/07/2007): Title 17 of the California Code of Regulations (CCR), sections 94200-94214.

This regulation defines "distributed generation (DG)" as electrical generation technologies that produce electricity near the place of use. "Digester gas" is defined as gases produced from the decomposition of sewage. "Combined heat and power (CHP)" is defined as a system that recovers thermal energy and converts it into useful heat from electrical power generation equipment. [17 CCR §94202]

17 CCR §94203(c) requires that on or after January 1, 2013, any DG Unit subject to this regulation and fueled by digester gas, landfill gas, or oil-field waste gas must be certified pursuant to 17 CCR §94204 to the emission standards in Table 3. DG Units that produce CHP may take a credit to meet the January 1, 2013. Credit shall be at the rate of one MW-hr for each 3.4 million Btu's of heat recovered. To take the credit, the following must apply:

(1) DG Units are sold with CHP technology integrated into a standardized package by the Applicant; and
(2) DG Units achieve a minimum energy efficiency of 60 percent.

***CARB – continued***

**Table 3**
**Waste Gas Emissions Standards**

| **Pollutant** | Emission Standards (lb/MW-hr) | |
|---|---|---|
| | On or after January 1, 2008 | On or after January 1, 2013 |
| NOx | 0.5 | 0.07 |
| CO | 6.0 | 0.10 |
| VOC | 1.0 | 0.02 |

This regulation requires any DG Unit manufactured, sold, leased, or operating in California after January 1, 2003, must be certified by CARB unless the DG Unit is not exempt from an APCD/AQMD's permitting requirements. [17 CCR §94201(d)].

As stated above, section 17 CCR §94201(d) of this regulation would not require DG Units subject to SMAQMD's permitting requirements, such as the engines subject to this BACT determination (BACT No. 363), to meet the DG emission standards shown in Table 3. However, SMAQMD would consider the DG emission standards as "achieved in practice" if there were DG certifications (aka CARB Executive Orders) published for digester gas-fired I.C. engines and such engines had been operating within California for over six months. As of May 21, 2024, there are no current or expired CARB Executive Orders published for DG, digester gas-fired I.C. engines.[9,10] That being said, SMAQMD does not consider the DG emission standards as achieved in practice for this minor source BACT evaluation.

[9] Current Distributed Generation Executive Orders. Current Certifications. https://ww2.arb.ca.gov/our-work/programs/dgcert/exec-orders, accessed on May 21, 2024.

[10] Archived Distributed Generation Executive Orders. Expired Certifications. https://ww2.arb.ca.gov/our-work/programs/dgcert/exec-orders/archived, accessed on May 21, 2024.

## Sacramento Metropolitan AQMD (SMAQMD)

**BACT**

Within SMAQMD's jurisdiction, BACT is required for emission increases greater than 0 lb/day for VOC, NOx, SOx, PM10 and PM2.5; emission increases greater than 550 lb/day for CO; and emission increases greater than 3.3 lb/day for lead. SMAQMD uses conventional rounding methods where 0.49 lb/day rounds down to 0 and 0.5 lb/day rounds up to 1.

Source: SMAQMD BACT Clearinghouse.

As stated in the introduction, BACT No. 363 is a new determination for I.C. prime power, spark-ignited engines fueled by digester gas or a blend of digester gas and natural gas, rated greater than 500 HP (367 KW), and operating at a non-major stationary source within Sacramento County. For the purposes of BACT determination No. 363, "digester gas" is defined as biogas produced from wastewater treatment facilities.

SMAQMD has several expired, permit-specific, minor source BACT determinations (BACT Nos. 223, 143, 120, and 67) for I.C. prime power, spark-ignited engines fueled by digester biogas produced from dairy manure. Unlike biogas from wastewater treatment facilities, biogas from dairy manure does not contain silica compounds that could form siloxanes. Since siloxanes come from human products, they would not be present in dairy manure. As mentioned in the introduction, siloxanes must be removed from the biogas stream; otherwise, the siloxanes would reduce the effectiveness of the catalyst in the APC device and also damage the engine. Since the expired BACTs were specific to prime power engines fueled by digester biogas from dairy manure, those determinations will not be considered in this evaluation because the standards are not applicable to this BACT determination (BACT No. 363) focused on digester gas produced from wastewater treatment facilities.

Therefore, SMAQMD does not have an active or expired BACT for this equipment category.

| **I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled** | |
|---|---|
| **VOC** | N/A – No BACT determinations found. |
| **NOx** | N/A – No BACT determinations found. |
| **SOx** | N/A – No BACT determinations found. |
| **PM10** | N/A – No BACT determinations found. |
| **PM2.5** | N/A – No BACT determinations found. |
| **CO** | N/A – No BACT determinations found. |

**T-BACT**

There are no T-BACT standards published in the clearinghouse for this category.

***SMAQMD – continued***

**RULE REQUIREMENTS**

Rule 412 – Stationary Internal Combustion Engines Located at Major Stationary Sources of NOx (06/01/1995): This rule applies to any stationary internal combustion engine rated at more than 50 BHP located at a major stationary source of NOx. This BACT evaluation is for I.C. prime power, spark-ignited engines fueled by digester gas or a blend of digester gas and natural gas, rated greater than 500 HP (367 KW), and operating at a non-major stationary source. Therefore, this rule is not applicable to this BACT determination.

Rule 404 – Particulate Matter (Amended 11/20/1984): This rule limits particulate matter emissions to less than 0.23 grams per dry standard cubic meter (0.1 grains per dry standard cubic foot).

Rule 406 – Specific Contaminants (Last Amended 12/06/1978): This rule limits sulfur emissions to less than 0.2% by volume, except as otherwise provided in Rule 420, calculated as sulfur dioxide ($SO_2$). This rule also limits combustion contaminants to less than 0.23 grams per dry standard cubic meter (0.1 grains per dry standard cubic foot) of gas calculated to 12% of carbon dioxide ($CO_2$).

Rule 419 – NOx from Miscellaneous Combustion Units (Amended 10/25/2018): This rule applies to any miscellaneous combustion unit or cooking unit with a total rated heat input capacity of 2 MMBtu/hr or greater that is located at a major stationary source of NOx and to any miscellaneous combustion unit or cooking unit with a total rated heat input capacity of 5 MMBtu/hr or greater that is not located at a major stationary source of NOx. However, Section 114.3 of Rule 419 states that the requirements of this rule do not apply to internal combustion engines.

Rule 420 – Sulfur Content of Fuels (Last Amended 08/13/1981): This rule limits the sulfur content of all gaseous fuels to less than 50 grains per 100 cubic foot, calculated as hydrogen sulfide ($H_2S$), or any liquid fuel or solid fuel having a sulfur content in excess of 0.5% by weight. Pipeline natural gas in Sacramento County has a sulfur content of approximately 0.22 grains per 100 cubic feet.

**South Coast AQMD (SCAQMD)**

**BACT**
Within SCAQMD's jurisdiction, BACT is required for emission increases that equal or exceed 1.0 lb/day for any nonattainment air contaminant, any ozone-depleting compound, or ammonia.

Source: SCAQMD BACT Guidelines (Part D) for Non-Major Polluting Facilities

As of April 15, 2024, the SCAQMD Search Tool for BACT Determinations at Non-Major Polluting Facilities resulted in one (1) BACT determination for stationary, non-emergency, landfill or digester gas-fired I.C. engines, rated greater than 50 BHP, driving electrical generators and operating at non-major sources. These BACT standards are shown in the table below.

***SCAQMD – continued***

| **I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled** | |
|---|---|
| **VOC** | 30 ppmvd @ 15% $O_2$ (A) |
| **NOx** | 11 ppmvd @ 15% $O_2$ (A) |
| **SOx** | 40 ppmv daily average (B),<br>or<br>40 ppmv monthly average and 500 ppmv 15-minute average (B) |
| **PM10** | N/A – No requirements are listed for PM10 |
| **PM2.5** | N/A – No requirements are listed for PM2.5 |
| **CO** | 250 ppmvd @ 15% $O_2$ (A) |

(A) Demonstrates compliance with SCAQMD Rule 1110.2.
(B) Demonstrates compliance with SCAQMD Rule 431.1 for sulfur content of fuel (calculated as $H_2S$) for sewage digester gas.

## T-BACT

There are no T-BACT standards published in the clearinghouse for this category.

## RULE REQUIREMENTS

Rule 431.1 – Sulfur Content of Gaseous Fuels (Last Amended 06/12/1998):
The purpose of this rule is to reduce sulfur oxides (SOx) emissions from the combustion of gaseous fuels in stationary equipment permitted by the SCAQMD. This rule defines "sewage digester gas" as any gas derived from the anaerobic decomposition of organic sewage within its containment. Table 1 of this rule shows the sulfur content requirements for sewage digester gas.

**Table 1 from Rule 431.1**
Concentration Limits as Measured Over the Averaging Periods
for Various Gaseous Fuels Containing Sulfur Compounds Calculated as $H_2S$

| Fuel Type | Sulfur Limits (ppmv) | Averaging Period | Compliance Date On or After |
|---|---|---|---|
| Refinery Gas<br>Small Refiners<br>Other Refiners | <br>40<br>40 | <br>4 hours<br>4 hours | <br>May 4, 1996<br>May 4, 1994 |
| Landfill Gas | 150 | Daily | June 12, 1998 |
| Sewage Digester Gas | 40<br>or<br>40 and<br>500 | Daily<br>or<br>Monthly and<br>15-minutes | November 17, 1995<br><br>November 17, 1995 |
| Other Gases | 40 | 4 hours | May 4, 1994 |

***SCAQMD – continued***

Rule 1110.2 – Emissions from Gaseous- and Liquid-Fueled Engines (Last Amended 11/03/2023):

Electrical generator engines must meet the requirements of Table IV; however, the engines specified in Section (d)(1)(L)(v) (e.g. landfill/digester gas engines) **do not need to comply with Table IV** if these engines comply with the requirements of Section (d)(1)(C). Effective January 1, 2017, stationary engines fired on landfill or digester gas (biogas) must not exceed the emission concentration limits of Table III-B.

| **Table III-A from Rule 1110.2<br>Concentration Limits for Landfill and Digester Gas (Biogas)-Fired Low-Use Engines** | | |
|---|---|---|
| **NOx (ppmvd)[1]** | **VOC (ppmvd)[2]** | **CO (ppmvd)[1]** |
| bhp ≥ 500: 36 x ECF[3]<br>bhp < 500: 45 x ECF[3] | Landfill Gas: 40<br>Digester Gas: 250 x ECF[3] | 2,000 |
| **Table III-B from Rule 1110.2<br>Concentration Limits for Landfill and Digester Gas (Biogas)-Fired Engines<br>Effective January 1, 2017** | | |
| **NOx (ppmvd)[1]** | **VOC (ppmvd)[2]** | **CO (ppmvd)[1]** |
| 11 | 30 | 250 |

1 Parts per million by volume, corrected to 15% oxygen on a dry basis.
2 Parts per million by volume, measured as carbon, corrected to 15% oxygen on a dry basis and averaged over the sampling time required by the test method.
3 ECF is the efficiency correction factor. See Rule 1110.2 for more details on how to calculate ECF.

Section (d)(1)(L)(i) of this rule requires all new non-emergency engines driving electrical generators to comply with the lb/MW-hr emission standards shown in Table IV, **unless the engine meets the requirements of Section (d)(1)(L)(v) and Section (d)(1)(C) mentioned above**.

| **Table IV from Rule 1110.2<br>Emission Standards for New Electrical Generation Devices** | | |
|---|---|---|
| **Pollutant** | **Emission Standard (lb/MW-hr) [1]** | **Concentration Limit [3] (ppmvd) [4]** |
| NOx | 0.07 | 2.5 |
| CO | 0.20 | 12 |
| VOC | 0.10 [2] | 10 |

1 The averaging time of the emission standard for VOC is the sampling time required by the test method.
2 Mass emissions of VOC shall be calculated using a ratio of 16.04 pounds of VOC per lb-mole of carbon.
3 Concentration limit is calculated using a 40% engine efficiency and no applied thermal credit.
4 Parts per million by volume, corrected to 15% oxygen on a dry basis.

## San Joaquin Valley APCD (SJVAPCD)

**BACT**
Within SJVAPCD's jurisdiction, BACT is required for emission increases greater than 2 lb/day.[11]

Source: SJVAPCD BACT Clearinghouse (searchable)

As of April 17, 2024, the SJVAPCD BACT Clearinghouse (PDF) resulted in two (2) rescinded BACT determinations for stationary, non-emergency, waste gas-fired I.C. engines. These rescinded BACT determinations did not specify if the engines were used for electrical generation or if the determination was originally applicable to non-major sources. Therefore, SJVAPCD does not have an active BACT for this equipment category.

| I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled | |
|---|---|
| **VOC** | N/A – No BACT determinations found. |
| **NOx** | N/A – No BACT determinations found. |
| **SOx** | N/A – No BACT determinations found. |
| **PM10** | N/A – No BACT determinations found. |
| **PM2.5** | N/A – No BACT determinations found. |
| **CO** | N/A – No BACT determinations found. |

**T-BACT**
There are no T-BACT standards published in the clearinghouse for this category.

**RULE REQUIREMENTS:**

Rule 4201 – Particulate Matter Concentration (Last Amended 12/17/1992): This rule limits PM emissions from any single source operation, dust, fumes, or total suspended PM to 0.1 grains per dry standard cubic foot of gas.

Rule 4301 – Fuel Burning Equipment (Last Amended 12/17/1992): This rule limits the emissions of $SO_2$, NOx, and combustion contaminants from fuel burning equipment. The rule defines fuel burning equipment as any furnace, boiler, apparatus, and stack used in the process of burning fuel for the primary purpose of producing heat or power by indirect heat transfer. I.C. engines are not listed as part of this rule definition; therefore, this rule is not applicable to this BACT evaluation.

Rule 4702 – Internal Combustion Engines (Last Amended 08/19/2021): This rule limits the emissions of NOx, CO, VOC, PM, and SOx from I.C. engines rated greater than or equal to 25 BHP. The rule defines waste gas as an untreated, raw gas derived through a natural process, such as anaerobic digestion, from the decomposition of organic waste at municipal solid waste landfills or publicly owned wastewater treatment facilities. The waste gas category includes landfill gas generated at landfills, digester gas generated at sewage treatment facilities, or a combination of the two.

[11] San Joaquin Valley APCD. New and Modified Stationary Source Review Rule. Rule 2201, Section 4.1 BACT Requirements. https://ww2.valleyair.org/media/zzslqswt/rule-2201.pdf, accessed on April 17, 2024.

***SJVAPCD – continued***

**Table 3** Emission Limits for a Spark-Ignited Internal Combustion Engine Rated at >50 bhp Used Exclusively in Non-AO (All ppmv limits are corrected to 15% oxygen on a dry basis). Emission Limits are effective according to the compliance schedule specified in Section 7.5, Table 8.

| Engine Type | NOx Limit (ppmv) | CO Limit (ppmv) | VOC Limit (ppmv) |
|---|---|---|---|
| **1. Rich-Burn** | | | |
| a. **Waste Gas Fueled** (≥ 50% total monthly heat input from waste gas based on HHV) | **11** | **2000** | **90** |
| b. Cyclic Loaded, Field Gas Fueled | 11 | 2000 | 90 |
| c. Limited Use | 11 | 2000 | 90 |
| d. Rich-Burn Engine, not listed above | 11 | 2000 | 90 |
| **2. Lean-Burn** | | | |
| a. Limited Use | 11 | 2000 | 90 |
| b. Lean-Burn Engine used for gas compression | 40 | 2000 | 90 |
| c. **Waste Gas Fueled** (≥ 50% total monthly heat input from waste gas based on HHV) | **40** | **2000** | **90** |
| d. Lean-Burn Engine, not listed above | 11 | 2000 | 90 |

As stated in Section 7.5.2 of Rule 4702, all non-agricultural operation (non-AO), spark-ignited engines at a stationary source subject to Table 3 or Section 8.0 emission limits, SOx control requirements of Section 5.7, and the SOx monitoring requirements of Section 5.11 must comply with the emission limits in Table 3 (shown above) by 12/31/2023.

Rule 4801 – Sulfur Compounds (Last Amended 12/17/1992): This rule limits the emissions of sulfur compounds to two-tenths (0.2) percent by volume calculated as $SO_2$, on a dry basis averaged over 15 consecutive minutes. EPA Method 8 and CARB Method 1-100 (Continuous Emission Stack Sampling) must be used to determine compliance with the rule limit.

**San Diego County APCD (SDAPCD)**

**BACT**

Within SDAPCD's jurisdiction, BACT is required for emission increases greater than or equal to 10 lb/day for VOCs, NOx, SOx and PM10.

***SDAPCD – continued***

Source: SDAPCD NSR Requirements for BACT – Guidance Document, Revised 11/2023 (PDF) and https://www.sdapcd.org/content/sdapcd/permits/BACT.html

As of May 9, 2024, the SDAPCD BACT search resulted in four (4) BACT determinations for stationary, non-emergency, non-cogeneration, I.C. engines. Two (2) determinations were for natural gas-fired engines, while the remaining two (2) were for diesel-fired engines. These determinations will not be considered in this evaluation because the standards are not applicable to SMAQMD's BACT determination (BACT No. 363) focused on digester gas-fueled, non-emergency, I.C. engines. Additionally, this evaluation for BACT No. 363 does not exclude cogeneration I.C. engines.

Therefore, SDAPCD does not have an active BACT for this equipment category.

| **I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled** | |
|---|---|
| **VOC** | N/A – No BACT determinations found. |
| **NOx** | N/A – No BACT determinations found. |
| **SOx** | N/A – No BACT determinations found. |
| **PM10** | N/A – No BACT determinations found. |
| **PM2.5** | N/A – No BACT determinations found. |
| **CO** | N/A – No BACT determinations found. |

**T-BACT**
There are no T-BACT standards published in the clearinghouse for this category.

**RULE REQUIREMENTS** (https://www.sdapcd.org/content/sdapcd/rules.html)

Rule 53 – Specific Air Contaminants (Rev. Effective 01/22/1997): This rule limits PM emissions from the burning of carbon-containing material to 0.10 grains per dry standard cubic foot (0.23 grams per dry standard cubic centimeter) at 12% $CO_2$ by volume.

Rule 62 – Sulfur Content of Fuels (Rev. Effective 10/21/1981): This rule limits the sulfur content in fuels to 10 grains of sulfur compounds, calculated as $H_2S$, per 100 cubic feet (0.23 grams sulfur, calculated as $H_2S$, per cubic meter) of dry gaseous fuel at standard conditions. This rule is applicable to all stationary fuel-burning equipment, except the following: the equipment listed in Rule 53.1, the combustion of sewage treatment plant digester gas, and the incineration of landfill gas. Since digester gas from sewage treatment facilities is exempt from this rule, the rule is not applicable to this BACT evaluation.

***SDAPCD – continued***

Rule 68 – Fuel-Burning Equipment – Oxides of Nitrogen (Rev. Effective 09/20/1994): This rule limits NOx emissions to 125 ppmvd at 3% $O_2$ and 240 mg/m$^3$ at 20°C for gaseous fuels. This rule applies to any non-vehicular, fuel-burning equipment that has a maximum heat input rating greater than or equal to 50 MMBtu/hr. In accordance with Rule 69.4.1(a)(2), digester gas-fueled stationary I.C. engines are not subject to this rule because they are subject to Rule 69.4.1. Additionally, Rule 68 would not apply to this BACT evaluation because the 3,681 HP (9.37 MMBtu/hr) engines that are subject to this BACT are smaller than 50 MMBtu/hr.

Rule 69.4.1 – Stationary Reciprocating Internal Combustion Engines (Rev. Effective 07/08/2020): This rule applies to stationary I.C. engines with a brake horsepower (BHP) rating equal to or greater than 50 BHP. An engine subject to or exempt from this rule by subsection (b)(1) shall not be subject to Rule 68.

Rule 69.4.1 defines "waste derived gaseous fuel" as gaseous fuel, including but not limited to, digester gas and landfill gas. The definition specifically excludes fossil derived gaseous fuel and synthesis gas (syngas).

Table (C) in subsection (d)(1)(ii) identifies the standards for gaseous fueled new or replacement non-emergency engines.

| **Table (C) - subsection(d)(1)(ii)** | **Standards for New or Replacement Non-Emergency Engines – Gaseous Fuel.** | | | |
|---|---|---|---|---|
| **Engine Type** | **Concentration Limit** | | | |
| | **NOx [1] (ppmv)** | **VOC [2] (ppmv)** | **CO [3] (ppmv)** | **Formaldehyde [4] (ppmv)** |
| Rich-burn engines using fossil derived gaseous fuel or gasoline | 11 | 60 | 270 | 70 |
| Rich-burn engines using **waste derived gaseous fuel** or syngas | **50** | **80** | **610** | **70** |
| Lean-burn engines using fossil derived gaseous fuel | 65 | 60 | 270 | 70 |
| Lean-burn engines using **waste derived gaseous fuel** or syngas | **65** | **80** | **610** | **70** |
| Rich-burn engines used exclusively in agricultural operations | 90 | 250 | 2000 | N/A |
| Lean-burn engines used exclusively in agricultural operations | 150 | 750 | 2000 | N/A |

[1] Calculated as nitrogen dioxide in ppmv corrected to 15% oxygen on a dry basis.

[2] Calculated as methane in ppmv corrected to 15% oxygen on a dry basis, excluding emissions of formaldehyde.

[3] Calculated as carbon monoxide in ppmv corrected to 15% oxygen on a dry basis.

[4] Calculated as formaldehyde in ppmv corrected to 15% oxygen on a dry basis.

**Bay Area AQMD (BAAQMD)**

**BACT**

Within BAAQMD's jurisdiction, BACT is required for emission increases greater than 10 lb/day for precursor organic compounds (POC), non-precursor organic compounds (NPOC), NOx, $SO_2$, PM10, and CO.

Source: BAAQMD BACT/TBACT Workbook

As of May 9, 2024, the BAAQMD BACT search resulted in one (1) BACT determination for stationary, biogas-fired, I.C. engines, rated equal to or greater than 50 BHP. The table below shows the current BACT standards for this equipment category, which supersede BACT document # 96.2.4 (dated 05/30/2013); please also refer to the email dated 5/30/2024 from BAAQMD staff in Attachment C.

| **I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled (A)** | | |
|---|---|---|
| **VOC (B)** | Technology Feasible / Cost Effective:<br>Achieved in Practice: | No standard<br>0.12 g/bhp-hr |
| **NOx (C)** | Technology Feasible / Cost Effective:<br>Achieved in Practice: | No Standard<br>0.12 g/bhp-hr |
| **SOx** | Technology Feasible / Cost Effective:<br>Achieved in Practice: | 100 ppmv of total sulfur in biogas<br>150 ppmv of total sulfur in biogas |
| **PM10** | Technology Feasible / Cost Effective:<br>Achieved in Practice: | 0.07 g/bhp-hr<br>0.10 g/bhp-hr |
| **PM2.5** | No Standard | |
| **CO** | Technology Feasible / Cost Effective:<br>Achieved in Practice: | No standard<br>0.89 g/bhp-hr |

(A) BAAQMD provided an update to their BACT standards for this equipment category on 5/30/2024. See the email correspondence in Attachment C. These updates have not been posted on their website or CARB's BACT Clearinghouse.

(B) BAAQMD uses the term "precursor organic compounds (POC)" rather than SMAQMD's preferred terminology of volatile organic compounds (VOC).

(C) For SCR systems, ammonia emissions (NH3) are limited to an exhaust concentration of 10 ppmvd @ 15% $O_2$.

**T-BACT**

Use of an oxidation catalyst achieving 50% or better control of reduction of formaldehyde emissions, which are a precursor organic compound and a toxic air contaminant.

***BAAQMD – continued***

**RULE REQUIREMENTS**

Regulation 6 – Particulate Matter, Rule 1 – General Requirements (Last Amended 08/01/2018): This rule limits Total Suspended Particulate (TSP) concentration from any source to less than or equal to 343 mg/dscm (0.15 grains/dscf) of exhaust gas volume.

Regulation 8 – Organic Compounds, Rule 2 – Miscellaneous Operations (Last Amended 5/04/2022): This rule limits precursor organic compounds (POC) emissions from miscellaneous operations to 6.8 kg/day (15 lb/day) and 300 ppm total carbon on a dry basis.

Regulation 9 – Inorganic Gaseous Pollutants, Rule 1 – Sulfur Dioxide (Last Amended 11/03/2021): This rule limits sulfur dioxide ($SO_2$) emissions from any source, other than a ship, to 300 ppm (dry). This rule also limits ground-level concentrations of $SO_2$ from any emission source, other than ships, to 0.5 ppm continuously for 3 consecutive minutes, or 0.25 ppm averaged over 60 consecutive minutes, or 0.05 ppm averaged over 24 hours.
Regulation 9 – Inorganic Gaseous Pollutants, Rule 8 – Nitrogen Oxides and Carbon Monoxide from Stationary Internal Combustion Engines (Amended 07/25/2007): This rule limits NOx and CO emissions from stationary I.C. engines with an output rated by the manufacturer greater than 50 BHP. This regulation defines waste derived fuel gas as sewage sludge digester gas or landfill gas. The emission limits for spark-ignited engines powered by waste derived fuels are shown below.

| **Subsection 302<br>Emission Limits for Spark-Ignited Engines Powered by Waste Derived Fuels** | | |
|---|---|---|
| **Engine Type** | **NOx Limit** | **CO Limit** |
| Lean-Burn | 70 ppmvd @ 15% $O_2$ | 2000 ppmvd @ 15% $O_2$ |
| Rich-Burn | 70 ppmvd @ 15% $O_2$ | 2000 ppmvd @ 15% $O_2$ |

**Other Air Districts: Santa Barbara County APCD (SBCAPCD)**

In addition to SMAQMD and the four largest Air Districts mentioned above, information from other Air Districts was reviewed only if EPA's or CARB's BACT Clearinghouse listed an applicable BACT from one of those agencies. Santa Barbara County APCD (SBCAPCD) had BACT standards for digester-fired engines listed in CARB's BACT Clearinghouse.

**BACT**
Within SBCAPCD's jurisdiction, BACT is required for emission increases greater than or equal to 25 lb/day for criteria pollutants, except for CO where BACT is required for emission increases greater than or equal to 150 lb/day.

***Other Air Districts: SBCAPCD – continued***

Source: https://www.ourair.org/bact/

As of May 9, 2024, the SBCAPCD BACT Clearinghouse search resulted in three (3) BACT guidelines for spark-ignited, gaseous-fueled I.C. engines. Two (2) guidelines were not applicable since they were specific to prime power engines fired on California Public Utility Commission (PUC) quality natural gas. The one (1) guideline established for digester gas-fired engines was also not applicable because the BACT was applied to one project for prime power engines fueled by digester gas produced from the anaerobic digestion of green and food waste at a major source landfill.[12]

These determinations will not be considered in this evaluation because the standards are not applicable to SMAQMD's minor source BACT determination (BACT No. 363), which is focused on prime power, I.C. engines fueled by digester gas produced from wastewater treatment facilities. Therefore, SBCAPCD does not have an active BACT for this equipment category.

| **I.C. Engine, Prime Power, Spark-Ignited, Digester Gas-Fueled** | |
|---|---|
| **VOC** | N/A – No BACT determinations found. |
| **NOx** | N/A – No BACT determinations found. |
| **SOx** | N/A – No BACT determinations found. |
| **PM10** | N/A – No BACT determinations found. |
| **PM2.5** | N/A – No BACT determinations found. |
| **CO** | N/A – No BACT determinations found. |

**T-BACT**
There are no T-BACT standards published in the clearinghouse for this category.

**RULE REQUIREMENTS**

Rule 304 – Particulate Matter – Northern Zone (Readopted 10/23/1978): This rule limits PM emissions to 0.3 grains per cubic foot of gas at standard conditions.

Rule 309 – Specific Contaminants (Readopted 10/23/1978):
This rule limits the emissions of any one or more of the following contaminants, in any state or combination, from a source. The contaminants and concentration limits at the point of discharge are as follows:

- Sulfur compounds calculated as $SO_2$: 0.2 percent, by volume.

[12] Santa Barbara County APCD BACT Clearinghouse Guideline 3.6 (rev 1.1). Digester Gas Fired Engines (1/15/2019). https://www.ourair.org/wp-content/uploads/BACT-Guideline-3.6.pdf, accessed on April 10, 2024.
Also, see email dated May 20, 2024 from SBCAPCD in Attachment C of SMAQMD's BACT 363 staff report.

***Other Air Districts: SBCAPCD – continued***

- Combustion Contaminants:
  - Northern Zone: 0.3 grains per cubic foot of gas calculated to 12% $CO_2$ at standard conditions.
  - Southern Zone: 0.1 grains per cubic foot of gas calculated to 12% $CO_2$ dioxide at standard conditions (except as specified in section D for incinerator burning).

- Fuel Burning Equipment:
  - 200 lb/hour of sulfur compounds, calculated as $SO_2$;
  - 140 lb/hour of NOx, calculated as $NO_2$;
  - 10 lb/hour of combustion contaminants derived from the fuel.

- Fuel Burning Equipment – NOx – Southern Zone:
  - For any non-mobile fuel burning article, machine, equipment or other contrivance, having a maximum heat input rate of more than 1,775 MMBtu/hr:
    - NOx limit for gaseous fuels: 125 ppm @ 3% $O_2$
    - NOx limit for liquid or solid fuels: 225 ppm @ 3% $O_2$

  The Fuel Burning Equipment NOx limits of Rule 309 would not apply to this BACT evaluation because the 3,681 HP (9.37 MMBtu/hr) engines that are subject to this BACT are rated less than 1,775 MMBtu/hr.

- Carbon Monoxide – Southern Zone: 2,000 ppmvd
  - The CO limit does not apply to I.C. engines.

Rule 310 – Odorous Organic Sulfides (Readopted 10/23/1978): This rule limits the emissions of $H_2S$ or organic sulfides (or a combination of both) from any source within one contiguous property. The emissions resulting in ground-level concentrations at any point at or beyond the property line of the source cannot exceed the concentrations shown in the following table.

| Concentration as $H_2S$ | Averaging Time |
|---|---|
| 0.06 ppmv | 3 minutes |
| 0.03 ppmv | 1 hour |

Rule 311 – Sulfur Content of Fuels (Readopted 10/23/1978): This rule limits sulfur in fuels by geographic zones within the SBCAPCD jurisdiction.

- Southern Zone limit:
  - Any gaseous fuel containing sulfur compounds cannot exceed 15 grains/100 cubic feet (calculated as $H_2S$ at standard conditions).
  - The sulfur content in any liquid or solid fuel cannot exceed 0.5% by weight.

- Northern Zone limit:
  - Any gaseous fuel containing sulfur compounds cannot exceed 50 grains/100 cubic feet (calculated as $H_2S$ at standard conditions).
  - The sulfur content in any liquid or solid fuel cannot exceed 0.5% by weight.

***Other Air Districts: SBCAPCD – continued***

Rule 333 – Control of Emissions from Reciprocating Internal Combustion Engines (Last Amended 06/19/2008): This rule applies to any engine rated equal to or greater than 50 BHP. Spark-ignited engines operating annually on 75% or more of landfill gas (on a volume basis) are exempt from this rule. Emergency standby engines and engines operating less than 200 hours/year are also exempt from this rule.

| Section E: Requirements – Emission Limits | | | |
|---|---|---|---|
| **Engine Type** | **Limit (ppmvd @ 15% $O_2$)** | | |
| | **NOx** | **VOC** | **CO** |
| **1a.** Rich-Burn Noncyclically-Loaded Spark Ignition Engines | 50 | 250 | 4,500 |
| **2a.** Lean-Burn Spark Ignition Engines, 50 ≤ BHP < 100 | 200 | 750 | 4,500 |
| **2b.** Lean-Burn Spark Ignition Engines, BHP ≥ 100 | 125 | 750 | 4,500 |
| **3.** Rich-Burn Cyclically-Loaded Spark Ignition Engines | 300 | 250 | 4,500 |
| **4a.** Compression Ignition Engines and Dual-Fuel Engines | 700 | 750 | 4,500 |

## Summary of Achieved in Practice Control Technologies

**Unit Conversion for Pollutant Emission Standards**

Depending on the agency, the pollutant emission standards were listed in either ppmvd @ 15% $O_2$ or g/bhp-hr. For purposes of comparison, the standards have been converted to both units using the Brake-Specific Fuel Consumption (BSFC) provided by the engine manufacturer for SacSewer's project. The conversion equivalencies are based on the Santa Barbara County APCD's Piston IC Engine Technical Reference Document (dated 11/01/2002). See Attachment D.

**Discussion of Control Technologies:**

The SacSewer digester gas-fired, lean-burn engines will be equipped with selective catalytic reduction (SCR) for NOx control. The facility will implement a biogas fuel pre-treatment system to clean/condition the biogas prior to its combustion in the engines. As mentioned in the introduction of this BACT Determination (BACT No. 363), the biogas fuel pre-treatment system removes siloxanes and $H_2S$, thereby preventing these substances from poisoning the catalyst used in the SCR device. The combination of these technologies has been determined to be the most effective at reducing NOx, VOC, CO, PM, and SOx emissions.

**NOx, VOC & CO**

**Rich-Burn Engines:**
Even though this BACT determination is specific to lean-burn engines, this section provides a brief discussion of NOx, VOC, and CO control technology for rich-burn engines. Rich-burn engines are characterized by using excess fuel in the combustion chamber during combustion (oxygen in exhaust typically ranges from 0.5%-0.6%), higher exhaust temperatures, higher NOx emissions (due to higher exhaust temperatures), more complete fuel consumption, and lower power density.[13]

The achieved in practice control method for rich-burn engines is non-selective catalytic reduction (NSCR), also commonly called a 3-way catalyst. NSCR reduces the emissions of NOx, VOC, and CO using one control device. The level of reduction for each pollutant depends on the air-to-fuel ratio that is driving the engine. As the air-to-fuel ratio gets leaner (more air), NOx emissions will decrease, but VOC and CO emissions will increase.

**Lean-Burn Engines:**
Lean-burn engines are characterized by using excess air in the combustion chamber (oxygen in exhaust is typically > 6%), lower exhaust temperature, lower NOx emissions, better fuel efficiency, and higher power density.[14]

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[13] Caterpillar. Lean-Burn Natural Gas Generator Sets. Rich-burn engine section. https://www.cat.com/en_US/by-industry/electric-power/Articles/White-papers/lean-burn-gas-generator-sets.html#:~:text=A%20rich%20burn%20engine%20is,exhaust%20is%20typically%20%3E6%25), accessed on 5/30/2024.

[14] Caterpillar. Lean-Burn Natural Gas Generator Sets. https://www.cat.com/en_US/by-industry/electric-power/Articles/White-papers/lean-burn-gas-generator-sets.html#:~:text=A%20rich%20burn%20engine%20is,exhaust%20is%20typically%20%3E6%25), accessed on 5/30/2024.

NOx emissions from lean-burn, spark-ignited engines can be reduced by leaning the air/fuel ratio of the engine and the use of good combustion practices. However, as the air/fuel ratio gets leaner (more air) and the NOx emissions decrease, the VOC and CO emissions will increase, and engine power will decrease. Therefore, emission reductions when operating lean-burn engines is a balance between these three pollutant levels and the engine power.

Unlike engines with a rich air/fuel ratio, an NSCR/3-way catalyst cannot be used on engines with a lean air/fuel ratio due to the composition of the exhaust stream. To achieve further NOx reduction, the air/fuel ratio would need to be further leaned, which increases other pollutants and compromises the engine's performance, or through an add-on Selective Catalytic Reduction (SCR) device using urea injection. As mentioned earlier, for biogas engines, the biogas must be cleaned/conditioned prior to combustion in the engine to prevent the siloxanes and $H_2S$ from poisoning the catalyst used in the SCR device and other APC devices. Additionally, the use of an oxidation catalyst can further reduce VOC and CO emissions.

**PM10 & PM2.5**

Typically, PM control for spark-ignited engines involves the use of clean fuels and good combustion practices. In evaluating emissions for permitting purposes, the SMAQMD assumes all PM emissions are PM2.5, and therefore, PM10 and PM2.5 standards are equivalent. For biogas-fueled engines, pre-treatment includes de-watering, filtering, and compressing the biogas.

**SOx**

Typically, SOx control for spark-ignited engines involves the use of clean fuels and good combustion practices. For biogas-fueled engines, $SO_2$ emissions are controlled by removing $H_2S$ from the biogas stream before the cleaned/conditioned biogas enters the I.C. engine to prevent the $H_2S$ from poisoning the catalyst used in the APC devices.

**Toxics**

HAPs are emitted as VOCs, and the same control technologies that control VOCs also control HAPs. Therefore, the achieved in-practice standards for HAPs are the same as for VOCs.

Due to NOx, VOC, and CO reductions being interdependent, determinations are ranked with an emphasis on NOx reduction, rather than individual emission levels for NOx, VOC, and CO. The SOx, PM10, and PM2.5 determinations are ranked by their individual emission levels. The following “achieved in practice” control technologies have been identified and are ranked based on stringency:

| SUMMARY OF ACHIEVED IN PRACTICE CONTROL TECHNOLOGIES (A) | | | |
|---|---|---|---|
| **Pollutant** | **Standard** in original units, as stated by the reference Source | **Standard** (ppm and g/hp-hr, or other applicable units) | **Source** (Regulation, Rule, or BACT) |
| **NOx** | 1. 11 ppmvd @ 15% $O_2$ | 1. 11 ppmvd @ 15% $O_2$, or 0.10 g/hp-hr | 1. SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| | 2. 0.12 g/hp-hr | 2. 13 ppmvd @ 15% $O_2$, or 0.12 g/hp-hr | 2. BAAQMD BACT Guideline 96.2.4 (5/30/2013) and email dated 5/30/2024 regarding updated BACT standards |
| | 3. 40 ppmvd @ 15% $O_2$ | 3. 40 ppmvd @ 15% $O_2$, or 0.37 g/hp-hr | 3. SJVAPCD Rule 4702 |
| | 4. 65 ppmvd @ 15% $O_2$ | 4. 65 ppmvd @ 15% $O_2$, or 0.60 g/hp-hr | 4. SDAPCD Rule 69.4.1 |
| | 5. 90% Control, or 65 ppmvd @ 15% $O_2$ | 5. 90% Control, or 65 ppmvd @ 15% $O_2$, or 0.60 g/hp-hr | 5. CARB BARCT Standards |
| | 6. 70 ppmvd @ 15% $O_2$ | 6. 70 ppmvd @ 15% $O_2$, or 0.65 g/hp-hr | 6. BAAQMD Reg 9, Rule 8 |
| | 7. 80% Control, or 125 ppmvd @ 15% $O_2$ | 7. 80% Control, or 125 ppmvd @ 15% $O_2$, or 1.16 g/hp-hr | 7. CARB RACT Standards |
| | 8. 125 ppmvd @ 15% $O_2$ | 8. 125 ppmvd @ 15% $O_2$, or 1.16 g/hp-hr | 8. SBCAPCD Rule 333 |
| | 9. 150 ppmvd @ 15% $O_2$, or 2.0 g/hp-hr | 9. 150 ppmvd @ 15% $O_2$, or 2.0 g/hp-hr | 9. US EPA 40CFR60 JJJJ |
| | 10. 140 lb/hr calc'd as $NO_2$ | 10. 140 lb/hr calc'd as $NO_2$ | 10. SBCAPCD Rule 309 |
| | 11. Not applicable | 11. Not applicable | 11. BAAQMD Reg 8, Rule 2 |
| **VOC** | 1. 30 ppmvd @ 15% $O_2$ | 1. 30 ppmvd @ 15% $O_2$, or 0.10 g/hp-hr | 1. SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |

| SUMMARY OF ACHIEVED IN PRACTICE CONTROL TECHNOLOGIES (A) | | | |
|---|---|---|---|
| **Pollutant** | **Standard** in original units, as stated by the reference Source | **Standard** (ppm and g/hp-hr, or other applicable units) | **Source** (Regulation, Rule, or BACT) |
| | 2. 0.12 g/hp-hr | 2. 36 ppmvd @ 15% $O_2$, or 0.12 g/hp-hr | 2. BAAQMD BACT Guideline 96.2.4 (5/30/2013) and email dated 5/30/2024 regarding updated BACT standards |
| | 3. 90 ppmvd @ 15% $O_2$ | 3. 90 ppmvd @ 15% $O_2$, or 0.29 g/hp-hr | 3. SJVAPCD Rule 4702 |
| | 4. 80 ppmvd @ 15% $O_2$, and 70 ppmvd @ 15% $O_2$ for Formaldehyde | 4. 80 ppmvd @ 15% $O_2$ (0.26 g/hp-hr) and 70 ppmvd @ 15% $O_2$ for Formaldehyde (0.42 g/hp-hr) | 4. SDAPCD Rule 69.4.1 |
| | 5. 750 ppmvd @ 15% $O_2$ | 5. 750 ppmvd @ 15% $O_2$, or 2.42 g/hp-hr | 5. CARB BARCT Standards |
| | 6. Not applicable | 6. Not applicable | 6. BAAQMD Reg 9, Rule 8 |
| | 7. 750 ppmvd @ 15% $O_2$ | 7. 750 ppmvd @ 15% $O_2$, or 2.42 g/hp-hr | 7. CARB RACT Standards |
| | 8. 750 ppmvd @ 15% $O_2$ | 8. 750 ppmvd @ 15% $O_2$, or 2.42 g/hp-hr | 8. SBCAPCD Rule 333 |
| | 9. 80 ppmvd @ 15% $O_2$, or 1.0 g/hp-hr, or | 9. 80 ppmvd @ 15% $O_2$, or 1.0 g/hp-hr | 9. US EPA 40CFR60 JJJJ |
| | 10. Not applicable | 10. Not applicable | 10. SBCAPCD Rule 309 |
| | 11. 15 lb/day and 300 ppmvd total carbon | 11. 15 lb/day and 300 ppmvd total carbon | 11. BAAQMD Reg 8, Rule 2 |
| **CO** | 1. 250 ppmvd @ 15% $O_2$ | 1. 250 ppmvd @ 15% $O_2$, or 1.41 g/hp-hr | 1. SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |

| SUMMARY OF ACHIEVED IN PRACTICE CONTROL TECHNOLOGIES (A) | | | |
|---|---|---|---|
| **Pollutant** | **Standard** in original units, as stated by the reference Source | **Standard** (ppm and g/hp-hr, or other applicable units) | **Source** (Regulation, Rule, or BACT) |
| | 2. 0.89 g/hp-hr | 2. 157 ppmvd @ 15% $O_2$, or 0.89 g/hp-hr | 2. BAAQMD BACT Guideline 96.2.4 (5/30/2013) and email dated 5/30/2024 regarding updated BACT standards |
| | 3. 2,000 ppmvd @ 15% $O_2$ | 3. 2,000 ppmvd @ 15% $O_2$, or 11.28 g/hp-hr | 3. SJVAPCD Rule 4702 |
| | 4. 610 ppmvd @ 15% $O_2$ | 4. 610 ppmvd @ 15% $O_2$, or 3.44 g/hp-hr | 4. SDAPCD Rule 69.4.1 |
| | 5. 4,500 ppmvd @ 15% $O_2$ | 5. 4,500 ppmvd @ 15% $O_2$, or 25.37 g/hp-hr | 5. CARB BARCT Standards |
| | 6. 2,000 ppmvd @ 15% $O_2$ | 6. 2,000 ppmvd @ 15% $O_2$, or 11.28 g/hp-hr | 6. BAAQMD Reg 9, Rule 8 |
| | 7. 4,500 ppmvd @ 15% $O_2$ | 7. 4,500 ppmvd @ 15% $O_2$, or 25.37 g/hp-hr | 7. CARB RACT Standards |
| | 8. 4,500 ppmvd @ 15% $O_2$ | 8. 4,500 ppmvd @ 15% $O_2$, or 25.37 g/hp-hr | 8. SBCAPCD Rule 333 |
| | 9. 610 ppmvd @ 15% $O_2$, or 5.0 g/hp-hr | 9. 610 ppmvd @ 15% $O_2$, or 5.0 g/hp-hr | 9. US EPA 40CFR60 JJJJ |
| | 10. Not applicable | 10. Not applicable | 10. SBCAPCD Rule 309 |
| | 11. Not applicable | 11. Not applicable | 11. BAAQMD Reg 8, Rule 2 |
| **PM10** | 1. 0.10 g/hp-hr | 1. 0.10 g/hp-hr | 1. BAAQMD BACT Guideline 96.2.4 (5/30/2013) |
| | 2. 0.1 grains/dscf | 2. 0.1 grains/dscf | 2. SMAQMD Rule 404, SJVAPCD Rule 4201 |

| SUMMARY OF ACHIEVED IN PRACTICE CONTROL TECHNOLOGIES (A) | | | |
|---|---|---|---|
| **Pollutant** | **Standard** in original units, as stated by the reference Source | **Standard** (ppm and g/hp-hr, or other applicable units) | **Source** (Regulation, Rule, or BACT) |
| | 3. 0.10 grains/dscf @ 12% $CO_2$ by volume. | 3. 0.10 grains/dscf @ 12% $CO_2$ by volume. | 3. SMAQMD 406, SDAPCD Rule 53 |
| | 4. 0.15 grains/dscf for Total Suspended Particulate | 4. 0.15 grains/dscf for Total Suspended Particulate | 4. BAAQMD Reg 6, Rule 1 |
| | 5. Southern Zone limit: 0.1 grains/cf @ 12% $CO_2$ Northern Zone limit: 0.3 grains/cf @ 12% $CO_2$ | 5. Southern Zone limit: 0.1 grains/cf @ 12% $CO_2$ Northern Zone limit: 0.3 grains/cf @ 12% $CO_2$ | 5. SBCAPCD Rule 309, SBCAPCD Rule 304 |
| | 6. 10 lb/hr combustion contaminants from fuel | 6. 10 lb/hr combustion contaminants from fuel | 6. SBCAPCD Rule 309 |
| **PM2.5** | **None** | **None** | **None** |
| **SOx** | 1. 40 ppmvd daily average, or 40 ppmvd monthly average <u>and</u> 500 ppmvd 15-minute average<br><br>For sulfur content of fuel (calculated as $H_2S$) for sewage digester gas. | 1. 40 ppmvd daily average, or 40 ppmvd monthly average <u>and</u> 500 ppmvd 15-minute average<br><br>For sulfur content of fuel (calculated as $H_2S$) for sewage digester gas. | 1. SCAQMD BACT (02/02/2018) and SCAQMD Rule 431.1 |
| | 2. 150 ppmvd total sulfur in biogas | 2. 150 ppmvd total sulfur in biogas | 2. BAAQMD BACT Guideline 96.2.4 (5/30/2013) |
| | 3. $SO_2$: 300 ppmvd and Ground-level $SO_2$: 0.5 ppm 3-min continuous, or 0.25 ppm 60-min average, or 0.05 ppm 24-hr average | 3. $SO_2$: 300 ppmvd and Ground-level $SO_2$: 0.5 ppm 3-min continuous, or 0.25 ppm 60-min average, or 0.05 ppm 24-hr average | 3. BAAQMD Reg 9, Rule 1 |
| | 4. $H_2S$ or organic sulfides ground-level concentrations at or beyond property line of source cannot exceed: 0.06 ppmv 3-min average and 0.03 ppmv 1-hr average | 4. $H_2S$ or organic sulfides ground-level concentrations at or beyond property line of source cannot exceed: 0.06 ppmv 3-min average and 0.03 ppmv 1-hr average | 4. SBCAPCD Rule 310 |

| SUMMARY OF ACHIEVED IN PRACTICE CONTROL TECHNOLOGIES (A) | | | |
|---|---|---|---|
| **Pollutant** | **Standard** in original units, as stated by the reference Source | **Standard** (ppm and g/hp-hr, or other applicable units) | **Source** (Regulation, Rule, or BACT) |
| | 5. 0.2% by volume calc'd as $SO_2$ | 5. 0.2% by volume calc'd as $SO_2$ | 5. SMAQMD Rule 406, SBCAPCD Rule 309 |
| | 6. 0.2% by volume calc'd as $SO_2$, 15-minute average | 6. 0.2% by volume calc'd as $SO_2$, 15-minute average | 6. SJVAPCD Rule 4801 |
| | 7. 0.2% by volume sulfur compounds, and 200 lb/hr calc'd as $SO_2$ | 7. 0.2% by volume sulfur compounds, and 200 lb/hr calc'd as $SO_2$ | 7. SBCAPCD Rule 309 |
| | 8. Southern Zone limit: 15 grains/100 cf calc'd as $H_2S$ Northern Zone limit: 50 grains/100 cf calc'd as $H_2S$ | 8. Southern Zone limit: 15 grains/100 cf calc'd as $H_2S$ Northern Zone limit: 50 grains/100 cf calc'd as $H_2S$ | 8. SBCAPCD Rule 311 |
| | 9. 50 grains / 100 cf calc'd as $H_2S$ | 9. 50 grains / 100 cf calc'd as $H_2S$ | 9. SMAQMD Rule 420 |
| | 10. 200 lb/hr calc'd as $SO_2$ | 10. 200 lb/hr calc'd as $SO_2$ | 10. SBCAPCD Rule 309 |
| **T-BACT** | Oxidation catalyst achieving ≥ 50% reduction of formaldehyde emissions | Oxidation catalyst achieving ≥ 50% reduction of formaldehyde emissions | BAAQMD BACT Guideline 96.2.4 (5/30/2013) |

(A) For NOx, VOC, and CO, determinations are ranked with an emphasis on NOx reductions, rather than the individual emission levels for NOx, VOC, and CO because of the interdependency of these pollutants. Therefore, some of the VOC and CO determinations may appear to be ranked out of order based on stringency. Additionally, if a BACT or rule only states a NOx standard, then "not applicable" will appear in the table under the same number ranking for VOC and CO. Please note that SOx, PM10, and PM2.5 determinations are ranked by their individual emission levels.

The following control technologies have been identified as the most stringent, achieved in practice control technologies:

| BEST CONTROL TECHNOLOGIES ACHIEVED (A) | | |
|---|---|---|
| **Pollutant** | **Standard** | **Source** |
| **VOC** | 30 ppmvd @ 15% $O_2$ (0.10 g/hp-hr) | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| **NOx** | 11 ppmvd @ 15% $O_2$ (0.10 g/hp-hr) | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| **SOx** | Sulfur content of fuel (calculated as $H_2S$):<br>40 ppmvd daily average,<br>or<br>40 ppmvd monthly average and<br>500 ppmvd 15-minute average | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| **PM10** | 0.10 g/hp-hr | BAAQMD BACT Guideline 96.2.4 (5/30/2013) |
| **PM2.5** | None | None |
| **CO** | 250 ppmvd @ 15% $O_2$ (1.41 g/hp-hr) | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| **T-BACT** | Oxidation catalyst achieving ≥ 50% reduction of formaldehyde emissions | BAAQMD BACT Guideline 96.2.4 (5/30/2013) |

## B. TECHNOLOGICALLY FEASIBLE AND COST EFFECTIVE (RULE 202, §205.1.b.)

**Technologically Feasible Alternatives:** Any alternative basic equipment, fuel, process, emission control device or technique, singly or in combination, determined to be technologically feasible by the Air Pollution Control Officer.

There are currently no technologically feasible alternatives identified as capable of reducing emissions beyond the levels determined to be "Achieved in Practice" as per Rule 202, §205.1.a.

| Pollutant | Technologically Feasible Alternatives |
|---|---|
| **VOC** | No other technologically feasible option was identified. |
| **NOx** | No other technologically feasible option was identified. |
| **SOx** | No other technologically feasible option was identified. |
| **PM10** | No other technologically feasible option was identified; however, BAAQMD BACT Guideline 96.2.4 (5/30/2013) lists a cleaner emission standard for PM10 (0.07 g/hp-hr) under the Technologically Feasible/Cost Effective category. This cleaner emission standard is achieved by using a biogas fuel pre-treatment technology, which is also the current "achieved in practice" technology for PM10. |
| **PM2.5** | No other technologically feasible option was identified. |
| **CO** | No other technologically feasible option was identified. |

**Cost Effective Determination:**
For minor source BACT categories, a cost effectiveness determination does not need to be performed for technology that SMAQMD has determined to be "Achieved in Practice." Additionally, a cost effectiveness determination does not need to be performed for technologically feasible alternatives if no other options have been identified for the regulated pollutants in the table above.

The analysis below summarizes the current technologically feasible standards and demonstrates that no technologically feasible alternatives are currently identified as capable of reducing emissions beyond the "Achieved in Practice" levels, except for PM10.

- The State of California's Distributed Generation (DG) Regulation (California Code of Regulations (CCR), Sections 94200-94214) set a NOx standard of 0.07 lb/MW-hr for waste gas-fired units that are installed on or after January 1, 2013. The DG program has not issued any Executive Orders (certifications) for waste gas-fired I.C. engines that meet this standard.

- The SJVAPCD BACT Guideline 3.3.19 sets a NOx standard that is equivalent to the DG standard for fossil-fueled engines used for electricity generation, which does not apply to waste gas-fired engines. SJVAPCD does not have a BACT for waste gas-fired engines.

***Technologically Feasible and Cost Effective – continued***

- The SCAQMD Rule 1110.2 (Emissions from Gaseous and Liquid Fueled Engines) set NOx, VOC, and CO emission standards equivalent to the DG standards for new non-emergency electrical generators. But under Section (d)(1)(v) of this rule, it exempts digester gas-fired engines from the DG-equivalent limits and subjects them to a NOx standard of 11 ppmvd @ 15% $O_2$, VOC standard of 30 ppmvd @ 15% $O_2$, and CO standard of 250 ppmvd @ 15% $O_2$. These standards for digester gas-fired engines became effective on January 1, 2017.

  However, it is important to note that the original effective date was July 1, 2012, under the February 1, 2008 version of Rule 1110.2. Subsequent amendments to this rule changed the effective date of these standards to allow SCAQMD time to conduct a technology assessment to ensure that these emission standards were achievable for waste gas-fired engines. SCAQMD staff reports for Rule 1110.2 stated that the rule's emission standards set for waste gas-fired engines were technology-forcing. There were several pilot studies performed to determine if SCR technology was feasible for waste gas-fired engines to achieve the Rule 1110.2 emission standards.

  A pilot study was performed on a waste gas-fired engine with an SCR system from April 1, 2010 to March 31, 2011, for the Orange County Sanitation District. The results of the July 2011 final report demonstrated that NOx emissions averaged 7.2 ppmvd @ 15% $O_2$, with some excursions above 11 ppmvd @ 15% $O_2$. Updates to the study from May 2014 to October 2014 showed average NOx emissions of 8.2 ppmvd @ 15% $O_2$.[15]

  Another pilot study was performed on a biogas-fired engine that used NOxTech technology at the Eastern Municipal Water District. NOxTech is a selective non-catalytic reduction (SNCR) control technology that treats the exhaust stream of I.C. engines and does not require biogas pre-treatment (cleaning/conditioning). On January 14, 2015, the results of the NOxTech system demonstrated the average NOx emissions to be within the 11 ppmvd @ 15% $O_2$ standard, with few results under 5 ppmvd @ 15% $O_2$.[16]

  For reference, the DG NOx standard is equivalent to 2.5 ppmvd @ 15% $O_2$. Therefore, SCAQMD's pilot studies (see Attachment E) demonstrated that waste gas-fired engines could achieve the Rule 1110.2 NOx emission standard of 11 ppmvd @ 15% $O_2$ using an SCR system or equivalent technology, and also demonstrated that it was not technologically feasible to achieve the DG NOx standard equivalent of 2.5 ppmvd @ 15% $O_2$.

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[15] SCAQMD Rule 1110.2 Biogas Technology Committee Meeting – October 29, 2014. Orange County Sanitation District Technology Demonstration Project Update. PowerPoint Presentation Slides. https://www.aqmd.gov/docs/default-source/rule-book/support-documents/rule-1110_2/ocsd_102914.pdf?sfvrsn=2, accessed 5/31/2024.

[16] SCAQMD Biogas User Group Meeting (January 14, 2015). TVRWRF NoxTech Project. PowerPoint Presentation Slides. https://www.aqmd.gov/docs/default-source/rule-book/support-documents/rule-1110_2/noxtech-update-january-2015.pdf?sfvrsn=2, accessed on 5/31/2024.

***Technologically Feasible and Cost Effective – continued***

In summary, the SacSewer project is proposing the use of an SCR system with a biogas fuel pre-treatment system, which is the most effective NOx reduction technology available for biogas-fired I.C. engines. The use of SCR with a biogas fuel pre-treatment system, or equivalent technology, to meet a NOx standard of 11 ppmvd @ 15% $O_2$ will be deemed as the highest achievable standard and has been determined to be "achieved in practice." Therefore, a cost effectiveness analysis is not required for the use of SCR or the biogas fuel pre-treatment system, and there is no other standard for using SCR with a biogas fuel pre-treatment system, or equivalent technology, that has been deemed technologically feasible for digester gas-fired engines operating at a minor source.

The PM10 emission standard (0.07 g/hp-hr) shown in the table above is achieved by using a biogas fuel pre-treatment technology, which is the most effective PM reduction technology available for biogas-fired I.C. engines. The use of a biogas fuel pre-treatment system to meet a PM10 standard of 0.07 g/hp-hr will be deemed as the highest achievable standard and has been determined to be "achieved in practice." Additionally, the project proposal for these digester engines has stated that each engine can meet the 0.07 g/hp-hr PM emissions limit; therefore, a cost effectiveness analysis is not necessary.

## C. SELECTION OF BACT:

Based on the review of SMAQMD, SCAQMD, SJVAPCD, SDAPCD, BAAQMD, SBCAPCD, CARB and US EPA BACT Clearinghouses, the BACT for I.C. Prime Power, Spark-Ignited Engines Fueled by Digester Gas or a Blend of Digester Gas and Natural Gas will be the following:

| **BACT # 363 for I.C. Prime Power, Spark-ignited, Lean-Burn Engines Fueled by Digester Gas or a Blend of Digester Gas and Natural Gas** | | |
|---|---|---|
| **Pollutant** | **Standard** | **Source** |
| **VOC** | 30 ppmvd @ 15% $O_2$ (0.10 g/hp-hr) | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| **NOx** | 11 ppmvd @ 15% $O_2$ (0.10 g/hp-hr) | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| **SOx** | Sulfur content of fuel (calculated as $H_2S$):<br>40 ppmvd daily average,<br>or<br>40 ppmvd monthly average and<br>500 ppmvd 15-minute average | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |
| **PM10** | 0.07 g/hp-hr | BAAQMD BACT Guideline 96.2.4 (5/30/2013) |
| **PM2.5 (A)** | 0.07 g/hp-hr | |
| **CO** | 250 ppmvd @ 15% $O_2$ (1.41 g/hp-hr) | SCAQMD BACT (02/02/2018) and SCAQMD Rule 1110.2 |

(A) All PM is expected to be less than 1.0 micrometer in diameter and, therefore, represents PM10 and PM2.5 emission factors.

***Selection of BACT – continued***

| T-BACT for I.C. Prime Power, Spark-ignited, Lean-Burn Engines<br>Fueled by Digester Gas or a Blend of Digester Gas and Natural Gas | | |
|---|---|---|
| **Pollutant** | **Standard**<br>(ppm and g/hp-hr, or other applicable units) | **Source** |
| **T-BACT (toxics)** | Oxidation catalyst achieving ≥ 50% reduction of formaldehyde emissions | BAAQMD BACT Guideline 96.2.4 (5/30/2013) |

**APPROVED BY:** Brian F Krebs **DATE:** 07-16-2024

# Attachment A

## Review of BACT Determinations published by US EPA

Technology Transfer Network
Clean Air Technology Center - RACT/BACT/LAER Clearinghouse

# RBLC Basic Search

**Choose the country/countries you wish to Search.**

Help

- [x] USA
- [ ] MEXICO
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Choose criteria from one or more of the groups listed below. You don't need to fill in all spaces. Default values are indicated.

Run search now | Reset form

( ) Show All (•) Show 150 records per page

**Other Search Options:**

**Permit Data Base**
Find Lowest Emission Rate
Standard Search
Advanced Search
RBLC ID Search
Greenhouse Gas Search

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Help

**PERMIT DATE**

From: 1/1/2013 (MM/DD/YYYY)

To: 01/30/2024 (MM/DD/YYYY)

Default = Last 10 years. Permits go back to 1970.

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Help

**PROCESS INFORMATION**

Process Type:
17.140 - Landfill/Digester/Bio-Gas
(All Process Type matches are Exact Matches)

Process Name Contains:

A blank box finds all processes under type specified above.

---

Help

**POLLUTANT NAME**

All Pollutants

---

Help

**CORPORATE/COMPANY OR FACILITY NAME CONTAINS:**

A blank box finds all company and plant names.

---

Help

**FACILITY STATE**

All States

---

( ) Show All (•) Show 150 records per page

Run search now | Reset form

Technology Transfer Network
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# RBLC Search Results

List of Reports Help

Your search has found **12** facilities and **15** processes that match your search criteria. You can view details for one or more facilities by clicking on the highlighted RBLC identifier or the process description in the list below. To create a report, select one of the standard output formats from the list of reports at the bottom of this page. Only facilities that are checked in the table below will be included in your report. Click on the check box next to any facility to switch between checked and unchecked or use the "Check" or "Un-Check" all facilities buttons at the top of the list to check or uncheck all records in the list.

Please note that the use of your browser's BACK button to change the search conditions may result in inaccurate results.

Matching Facilities for Search Criteria : Tips
Permit Date Between 1/1/2013 And 01/30/2024
And Process Type = 17.140

**These results are for USA only.**

Check Un-Check **ALL Facilities** New Search

NOTE: Draft determinations are marked with a " * " beside the RBLC ID.

| RBLC ID | CORPORATE/COMPANY & FACILITY NAME | PROCESS CODE | PROCESS DESCRIPTION | PERMIT NUMBER & PERMIT DATE |
|---|---|---|---|---|
| Sort By | Sort By | | | Sort By |
| IN-0360 | LIBERTY LANDFILL, LLC<br>LIBERTY LANDFILL, LLC | 17.140 | Landfill gas-fired engine generator sets | 181-45869-00035<br>11/30/2022 |
| CA-1241 | TAJIGUAS LANDFILL | 17.140 | ICE Landfill or digested gas fired | 14500<br>08/19/2016 |
| ME-0041 | JUNIPER RIDGE ENERGY LLC<br>JUNIPER RIDGE LANDFILL | 17.140 | Engine #1 | A-1116-77-1-A<br>03/30/2016 |
| | | 17.140 | Engine #2 | |
| | | 17.140 | Engine #3 | |
| VT-0040 | COVENTRY CLEAN ENERGY CORPORATION<br>COVENTRY MUNICIPAL SOLID WASTE FACILITY | 17.140 | Stationary Internal Combustion Engine | AOP-15-032<br>03/04/2016 |
| IN-0246 | WASTE MANAGEMENT SERVICE CENTER<br>LIBERTY LANDFILL, INC. | 17.140 | LANDFILL GAS-FIRED ENGINE GENERATOR SETS | 181-33869-00035<br>10/22/2015 |
| MI-0419 | WASTE MANAGEMENT, INC.<br>WASTE MANAGEMENT, INC.--PINE TREE ACRES LANDFILL | 17.140 | FGICENGINES | 160-14<br>02/13/2015 |
| FL-0339 | OMNI WASTE OF OSCEOLA COUNTY, LLC<br>JED SOLID WASTE MANAGEMENT FACILITY | 17.140 | 12 LFG-fired RICE/generator sets, 1.6 MW each | 0970079-011-AC<br>09/15/2014 |
| IL-0113 | HOOSIER ENERGY REC, INC.<br>HOOSIER ENERGY | 17.140 | Engines | 11050042<br>12/23/2013 |
| FL-0345 | LANDFILL ENERGY SYSTEMS FLORIDA, LLC<br>SARASOTA LANDFILL GAS-TO-ENERGY | 17.140 | Four landfill gas-to-energy engines | 1150089-008-AC<br>12/18/2013 |
| MI-0411 | NORTH AMERICAN NATURAL RESOURCES, INC.<br>VENICE PARK RECYCLING & DISPOSAL FACILITY | 17.140 | FGENGINES7R-10 (4 CAT engines using landfill gas) | 123-11A<br>12/11/2013 |
| CA-1227 | CITY OF SAN DIEGO, PUBLIC UTILITIES DEPT.<br>CITY OF SAN DIEGO, PUBLIC UTILITIES DEPT. | 17.140 | ICE LANDFILL GAS FIRED ENGINE | APCD2011-APP-001659<br>09/25/2013 |
| *OR-0052 | WASTE MANAGEMENT DISPOSAL SERVICES OF OREGON, INC.<br>COLUMBIA RIDGE LANDFILL AND RECYCLING CENTER | 17.140 | Caterpillar 3520C internal combustion engines which drive electric generators | 11-0001-ST-02<br>06/21/2013 |
| | | 17.140 | Caterpillar 3516 internal combustion engines which drive electric generators | |

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- ○ Process Type Summary(with Agency Contact Info) ◉ TXT ○ pdf
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- ○ Free Form Report(Customizable Fields Selection)
- ○ Free Form Report ◉ TXT ○ pdf
- ○ Export/Import Report(ASCII Delineated Text)

Create report

**RBLC ID: IN-0360**
**Permit #: 181-45869-00035**
**Permit Date: 11/30/2022**

Process: IC Engine for GenSet, Lean-Burn, primary fuel = LFG, size = 2233 BHP (1.6 MW), max heat input capacity = 18.20 MMBtu/hr.

Four (4) treated landfill gas-fired 4-stroke Lean-Burn spark ignition reciprocating internal combustion engine (RICE) generator sets, identified as emission units EG9, EG10, EG11, EG12, constructed in 2016, each rated at 2,233 BHP (output), 1.6 MW, and a maximum heat input capacity of 18.20 MMBtu/hr.

**BACT:**
TPM2.5 = 0.2 g/hp-hr (based on a 3-hr average),

PM2.5 controlled by mist elimination system 95% control efficiency.

**RBLC ID: CA-1241**
**Permit #: 14500**
**Permit Date: 08/19/2016**

Process: IC Engine for GenSet, _____, LFG or Digester Gas Fired ICE, primary fuel = Digester Gas, size = 1573 BHP

**BACT:**
VOC = permit limit is case-by-case and not based on BACT (26 ppmv @ 15% O2),
NOx = permit limit is case-by-case and not based on BACT (9 ppmv @ 15% O2),
SOx = permit limit is case-by-case and not based on BACT (28 ppmv @ 15% O2),
Filterable PM10 = permit limit is case-by-case and not based on BACT (0.118 g/hp-hr),
Filterable PM2.5 = permit limit is case-by-case and not based on BACT (0.118 g/hp-hr),
CO = permit limit is case-by-case and not based on BACT (36 ppmv @ 15% O2),
Ammonia (NH3) = permit limit is case-by-case and not based on BACT (5 ppm @ 15% O2),

**RBLC ID: ME-0041**
**Permit #: A-1116-77-1-A**
**Permit Date: 03/30/2016**

Engine #1, 2, and 3
Process: IC Engine for GenSet, _____, primary fuel = LFG, throughput = 16.5 MMBtu/hr
**BACT:**
NOx = 0.6 g/hp-hr (2.97 lb/hr),
PM10 = 1.2 lb/hr,
PM2.5 = 1.2 lb/hr,
CO = 3.5 g/hp-hr (17.3 lb/hr),

**RBLC ID: VT-0040**
**Permit #: AOP-15-032**
**Permit Date: 03/04/2016**

Process: IC Engine for GenSet, _____, primary fuel = LFG, size = 2221 HP (1600kW), throughput = 507 scfm (totaling 2535 cfm)

Five (5) internal combustion engines, each driving an electrical generator.
Each genset is the same: Caterpillar G3520C LE rated at 2,221 HP (1600kW), burning 507 scfm (totaling 2535 cfm) of landfill gas.

**BACT:**
CO = permit limit is case-by-case and not based on BACT (3.5 g/hp-hr [17.3 lb/hr]).

The above noted limits for CO are to be achieved at all times. To help ensure the engines are being properly maintained which includes the cleaning of the siliceous deposits that form in the engine cylinders due to the siloxanes present in the LFG, the following limits must also be demonstrated through periodic testing:
Every 2 years: 3.1 g/hp-hr (15.3 lb/hr).
Every 6 years: 2.75 g/hp-hr (13.5 lb/hr).

To keep the engine's CO emissions as low as reasonably possible, the build up of siliceous deposits in the engine combustion chambers must be periodically serviced/cleaned. It is anticipated to require annual cleaning, as well as a more extensive on-site in-frame cleaning every 3 years, as well as a more extensive off-site overhaul every 6 years.

**RBLC ID: IN-0246**
**Permit #: 181-33869-00035**
**Permit Date: 10/22/2015**

Process: IC Engine for GenSet, _____, primary fuel = LFG, size = 2233 BHP (1.6 MW), max heat input capacity = 18.20 MMBtu/hr.

Four (4) treated landfill gas-fired 4-stroke Lean-Burn spark ignition reciprocating internal combustion engine (RICE) generator sets, identified as emission units EG9, EG10, EG11, EG12, approved in 2015 for construction, each rated at 2233 BHP (output), 1.6 MW, and a maximum heat input capacity of 18.20 MMBtu/hr.

**BACT:**
NOx = 0.6 g/hp-hr (based on a 3-hr average),
TPM2.5 = 23.3 lb/MMcf, CH4 dry based on a 3-hr average, PM2.5 controlled by mist elimination system 95% control efficiency.
CO = 3.3 g/hp-hr (based on a 3-hr average),
Methane (CH4) = 0.0032 kg/MMBtu (based on a 3-hr average).

**RBLC ID: MI-0419**
**Permit #: 160-14**
**Permit Date: 02/13/2015**

8 IC engines, BACT limit is for each engine.
Process: IC Engine for GenSet, _____, primary fuel = LFG, throughput = 541 SCFM each
**BACT:**
SO2 = 3.51 lb/hr (based on a worst case sulfur concentration of 600 ppm)

**RBLC ID: FL-0339**
**Permit #: 0970079-011-AC**
**Permit Date: 09/15/2014**

12 IC engines, BACT limit is for each engine, 1.6 MW
Process: IC Engine for GenSet, _____, primary fuel = LFG, throughput = 14.96 MMBtu/hr, LHV
**BACT:**
VOC = 0.56 g/hp-hr (0.8 lb/hr)
NOx = 0.6 g/hp-hr (3.0 lb/hr),
CO = 3.5 g/hp-hr (17.3 lb/hr),

VE = 10% opacity continuous

**RBLC ID: IL-0113**
**Permit #: 11050042**
**Permit Date: 12/23/2013**

IC engines, BACT limit is for each engine
Process: IC Engine for GenSet, _____, primary fuel = LFG, size = 2.7 MW each, up to six (6) engines

**BACT:**
VOC = 0.71 g/hp-hr (3-hr average),
NOx = 0.6 g/hp-hr (3-hr average),
TPM = 0.1 g/hp-hr (3-hr average),
CO = 2.5 g/hp-hr (3-hr average),

**RBLC ID: FL-0345**
**Permit #: 1150089-008-AC**
**Permit Date: 12/18/2013**

4 IC engines, BACT limit is for each engine,
Process: IC Engine for GenSet, Lean-Burn, primary fuel = LFG, size = 2242 BHP (1600 kW), max heat input rating for each engine is 16.61 MMBtu/hour. maximum fuel consumption rate of each engine is 554 scfm.

**BACT:**
NOx = 0.6 g/hp-hr (3.0 lb/hr), More stringent than NSPS JJJJ standard of 2.0 g/bhp-hr.
TPM2.5 = 0 (Non-numerical work practice standards. Emissions of PM2.5 and PM10 expected to be less than 0.24 g/bhp-hr, even after engine wear.)
CO = 3.5 g/hp-hr (17.3 lb/hr), More stringent than NSPS JJJJ standard of 5.0 g/bhp-hr.

4 identical engines/generators sets; 2242 bhp per engine; 1600 kW per generator.
maximum fuel consumption rate of each engine is 554 scfm or 33,240 scf per hour.
Based on a LFG HHV of 500 Btu/scf, the maximum heat input rating for each engine is 16.61 MMBtu/hour (14.96 MMBtu/hour LHV).

four lean-burn internal combustion engines (Caterpillar model G3520C). Each engine is connected to a 1,600 kW generator.

**RBLC ID: MI-0411**
**Permit #: 123-11-A**
**Permit Date: 12/11/2013**

4 IC engines, BACT limit is for each engine.
Process: IC Engine for GenSet, _____, primary fuel = LFG, throughput = 1600 KW
**BACT:**
VOC = 0.63 g/hp-hr,
CO = 3.3 g/hp-hr (16.3 lb/hr),

4 Caterpillar landfill gas fueled engines used for electricity generation.
Engines are >500hp. Engines are subject to NSPS JJJJ and are "new" engines under NESHAP ZZZZ.

**RBLC ID: CA-1227**
**Permit #: APCD2011-APP001659**
**Permit Date: 09/25/2013**

Process: IC Engine for GenSet, _____, primary fuel = LFG, size = 2233 BHP
**BACT:**
VOC = permit limit is case-by-case and not based on BACT (20 ppmv @ 15% O2),
NOx = permit limit is case-by-case and not based on BACT (0.5 g/hp-hr)

**RBLC ID: OR-0052**
**Permit #: 11-0001-ST-02**
**Permit Date: 6/21/2013**

Engine #1 of 2 (Caterpillar 3520c
Process: IC Engine for GenSet, Lean-Burn, primary fuel = LFG, throughput = 2328 MMdscf/year
**BACT:**
VOC = 20 ppm dry basis as hexane @ 3% O2 (23.5 lb/MMdscf),
NOx = 0.6 g/hp-hr (2.954 lb/hr),
SO2 = 300 ppmv @ 98% DRE (49.91 lb/MMdscf),
TPM = 0.1 g/hp-hr (0.492 lb/hr),
CO = 3.6 g/hp-hr (17.72 lb/hr),
H2S = 300 ppmv @ 98% DRE (0.53 lb/MMdscf)

Engine #2 of 2 (Caterpillar 3516)
Process: IC Engine for GenSet, Lean Burn, primary fuel = LFG, throughput = 1400 MMdscf/year
**BACT:**
VOC = permit limit is not based on BACT (5.4 lb/MMdscf),
NOx = 1.45 g/hp-hr (183.8 lb/MMdscf),
TPM = 0.1 g/hp-hr (0.253 lb/hr),
CO = 2.5 g/hp-hr (285.9 lb/MMscf).

# Attachment B

## Review of BACT Determinations published by CARB

## List of BACT determinations published in CARB's BACT Clearinghouse for I.C. prime power, spark-ignited engines fueled by digester gas or biogas (as of April 10, 2024)

| Air District | Rating (BHP) | Fuel | Engine Burn Type | Other Details | Pollutant | Standard | Control Technology | Source Type |
|---|---|---|---|---|---|---|---|---|
| SBCAPCD | 1,573<br><br>(but there is no upper limit on the HP for this BACT) | Digester Gas | Not Mentioned | Application No. 14500-02<br><br>Digester Gas produced from foodwaste & greenwaste at a landfill. | VOC | 26 ppmv @ 15% $O_2$ ; 0.12 g/hp-hr | Digester Gas Cleaning System, Selective Catalytic Reduction, and Catalytic Oxidizer | Major |
| | | | | | NOx | 9 ppmv @ 15% $O_2$ ; 0.12 g/hp-hr | | |
| | | | | | SOx | case-by-case | | |
| | | | | | PM10 | case-by-case | | |
| | | | | | PM2.5 | case-by-case | | |
| | | | | | CO | 38 ppmv @ 15% $O_2$ ; 0.300 g/hp-hr | | |
| | | | | | Other:<br>NH3 (ammonia slip) | 5 ppmv @ 15% $O_2$ | | |

| Air District | Rating (BHP) | Fuel | Engine Burn Type | Other Details | Pollutant | Standard | Control Technology | Source Type |
|---|---|---|---|---|---|---|---|---|
| SCAQMD | 3,471 | Digester Gas and/or Natural Gas | Not Mentioned | Application No. 546360 | VOC | 30 ppmv @ 15% $O_2$ | Digester Gas Cleaning System, Selective Catalytic Reduction, and Catalytic Oxidizer | Major |
| | | | | | NOx | 11 ppmv @ 15% $O_2$ | | |
| | | | | | SOx | 40 ppmvd daily average,<br>or<br>40 ppmvd monthly average<br>and 500 ppmvd 15-minute average. | | |
| | | | | | PM10 | Rule 404 | | |
| | | | | | PM2.5 | Rule 404 | | |
| | | | | | CO | 250 ppmv @ 15% $O_2$ | | |
| | | | | | Other:<br>H2S (hydrogen sulfide) | see SOx standard. | | |

| Air District | Rating (BHP) | Fuel | Engine Burn Type | Other Details | Pollutant | Standard (A) | Control Technology | Source Type |
|---|---|---|---|---|---|---|---|---|
| BAAQMD | ≥ 50 HP | Biogas | Not Mentioned | digester and landfill gas are subject to the same standards. | VOC (B) | 0.12 g/hp-hr (Tech Feasible/Cost Effective);<br>0.16 g/hp-hr (Achieved in Practice) | Biogas PreTreatment System, Selective Catalytic Reduction, and Oxidation Catalyst<br><br>or<br><br>Biogas PreTreatment System, NOx Tech Selective Non-Catalytic Reduction, and Oxidation Catalyst | Minor |
| | | | | | NOx | 0.15 g/hp-hr (Achieved in Practice) | | |
| | | | | | SOx | 100 ppmv total sulfur in biogas (Tech Feasible/Cost Effective);<br>150 ppmv total sulfur in biogas (Achieved in Practice) | | |
| | | | | | PM10 | 0.07 g/hp-hr (Tech Feasible/Cost Effective);<br>0.10 g/hp-hr (Achieved in Practice) | | |
| | | | | | PM2.5 | None | | |
| | | | | | CO | 0.89 g/hp-hr (Tech Feasible/Cost Effective);<br>1.8 g/hp-hr (Achieved in Practice) | | |
| | | | | | Other:<br>NH3 (ammonia slip) | 10 ppmv @ 15% $O_2$ | | |

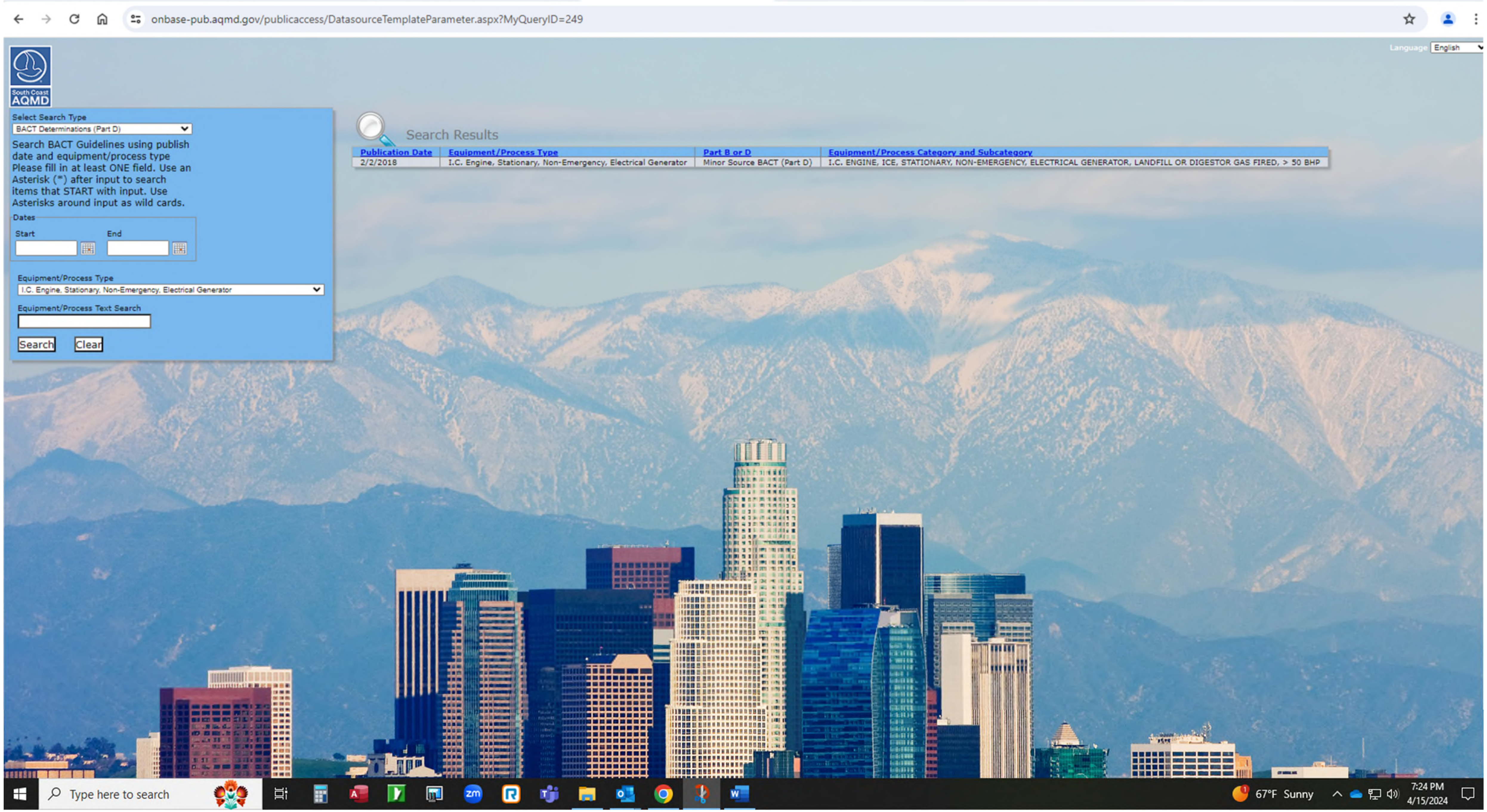
(A) These were the BACT standards listed on CARB's BACT Clearinghouse, but these are not the most current BAAQMD BACT standards for this equipment category. BAAQMD provided SMAQMD with an update to their BACT standards via email dated 5/30/2024 (see Attachment C). See the BAAQMD section of this evaluation for further details.

(B) BAAQMD uses the term "precursor organic compounds (POC)" rather than SMAQMD's preferred terminology of volatile organic compounds (VOC).

| Air District | Rating (BHP) | Fuel | Engine Burn Type | Other Details | Pollutant | Standard | Control Technology | Source Type |
|---|---|---|---|---|---|---|---|---|
| SBCAPCD | 510 | Digester Gas Only | Lean Burn | Application No. 12875 | VOC | 28 ppmv @ 15% $O_2$ | Digester Gas Fuel PreTreatment System,<br>and Air-to-Fuel Ratio Controller | Not mentioned,<br>but the permit evaluation stated that their BACT threshold (25 lb/day) was exceeded for NOx. |
| | | | | | NOx | 35 ppmv @ 15% $O_2$ | | |
| | | | | | SOx | Not mentioned. | | |
| | | | | | PM10 | Not mentioned. | | |
| | | | | | PM2.5 | Not mentioned. | | |
| | | | | | CO | 333 ppmv @ 15% $O_2$ | | |
| | | | | | Other: | Not mentioned. | | |

# Attachment C

## Review of BACT Determinations published by APCDs / AQMDs


onbase-pub.aqmd.gov/publicaccess/DatasourceTemplateParameter.aspx?MyQueryID=249
Language English
South Coast AQMD
Select Search Type
BACT Determinations (Part D)
Search BACT Guidelines using publish date and equipment/process type Please fill in at least ONE field. Use an Asterisk (*) after input to search items that START with input. Use Asterisks around input as wild cards.
Dates
Start
End
Equipment/Process Type
I.C. Engine, Stationary, Non-Emergency, Electrical Generator
Equipment/Process Text Search
Search
Clear
Search Results
Publication Date
Equipment/Process Type
Part B or D
Equipment/Process Category and Subcategory
2/2/2018
I.C. Engine, Stationary, Non-Emergency, Electrical Generator
Minor Source BACT (Part D)
I.C. ENGINE, ICE, STATIONARY, NON-EMERGENCY, ELECTRICAL GENERATOR, LANDFILL OR DIGESTOR GAS FIRED, > 50 BHP
Type here to search
67°F Sunny
7:24 PM
4/15/2024

2-2-2018 Rev. 0

Equipment or Process: I.C. Engine, Stationary, Non-Emergency, Electrical Generators [1]

| | Criteria Pollutants | | | | | |
|---|---|---|---|---|---|---|
| **Subcategory/ Rating/Size** | **VOC** | **NOx** | **SOx** | **CO** | **PM10** | **Inorganic** |
| > 50 bhp | Compliance with SCAQMD Rule 1110.2 (2-2-2018) | Compliance with SCAQMD Rule 1110.2 (2-2-2018) | See Clean Fuels Policy in Part C of the BACT Guidelines (2-2-2018) | Compliance with SCAQMD Rule 1110.2 (2-2-2018) | See Clean Fuels Policy in Part C of the BACT Guidelines (2-2-2018) Compliance with Rule 1470 (2-2-2018) | |
| Landfill or Digester Gas Fired | Compliance with SCAQMD Rule 1110.2 (2-2-2018) | Compliance with SCAQMD Rule 1110.2 (2-2-2018) | Compliance with SCAQMD Rule 431.1 (2-2-2018) | Compliance with SCAQMD Rule 1110.2 (2-2-2018) | | |

1) This BACT listing was adapted from the previous "I.C. Engine, Stationary, Non-Emergency," Part D BACT listing.

* Means those facilities that are not major polluting facilities as defined by Rule 1302 - Definitions

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## Joanne Chan

**From:** Joanne Chan
**Sent:** Thursday, May 30, 2024 4:18 PM
**To:** Brenda Cabral
**Cc:** Sanjeev Kamboj; Ali Othman; Felix Trujillo Jr.; Jeff Weiss
**Subject:** RE: Bay Area AQMD's BACT Determination for Biogas Fired IC Engines

Hello Brenda,

Thank you for answering our questions and providing updated information on the Bay Area AQMD's BACT standards for this equipment category. We appreciate your help.

Best regards,

**Joanne Chan**
Permitting
Engineering & Compliance Division
Sac Metro Air District
Direct: (279) 207-1173
JChan@airquality.org
www.AirQuality.org
@AQMD
SACRAMENTO METROPOLITAN AIR QUALITY MANAGEMENT DISTRICT

---

**From:** Brenda Cabral <BCabral@baaqmd.gov>
**Sent:** Thursday, May 30, 2024 11:29 AM
**To:** Joanne Chan <JChan@airquality.org>
**Cc:** Sanjeev Kamboj <Skamboj@baaqmd.gov>
**Subject:** FW: Bay Area AQMD's BACT Determination for Biogas Fired IC Engines



---

Hi, Ms. Chan: Thanks for your inquiry.

1. Yes, these standards are for prime engines. We have no emergency biogas engines.
2. These standards have been used for POTW digester gas engines. We have no permitted manure digesters or manure digester gas engines. But if we did, I am sure that these standards would apply.
3. We do issue permits with these standards for non-major sources. Our BACT threshold is 10 lb/day for POC, NOx, CO, SO2, PM10, PM2.5, and NPOC.

I can tell you that we now consider the following limits to be achieved in practice:
NOx: 0.12 g/bhp-hr
CO: 0.89 g/bhp-hr
POC: 0.12 g/bhp-hr

One facility has just agreed to 0.7 g CO/bhp-hr after a cost-effectiveness analysis, so that would be BACT 1 for them. Another facility has agreed to 0.11 g CO/bhp-hr without being subject to BACT. Neither of these would be considered to be achieved in practice.

If the engine emits more than 10 lb SO2/day, we would probably go to 50 ppmv of total sulfur in biogas, since some facilities are achieving that level.

We consider that both digester gas and landfill gas are subject to the same standards, but that is being disputed by the landfill gas engine owners. We may end up with different standards for landfill gas.

Please write or call me w/any additional questions.

Yours truly,

Brenda Cabral
Supervising Air Quality Engineer

BAAQMD
415-749-4686

---

**From:** Nicholas Maiden <nmaiden@baaqmd.gov>
**Sent:** Friday, May 24, 2024 5:49 PM
**To:** Carol Allen <CAllen@baaqmd.gov>; Sanjeev Kamboj <Skamboj@baaqmd.gov>
**Subject:** FW: Bay Area AQMD's BACT Determination for Biogas Fired IC Engines

Hi Carol and Sanjeev,

I received an enquiry (see email below) from Sac Metro regarding our BACT Workbook guideline for biogas fired ICE.

Would you or one of your staff please look into and respond to the email?

Thank you,
Nick

---

**From:** Joanne Chan <JChan@airquality.org>
**Sent:** Monday, May 20, 2024 11:20 AM
**To:** Nicholas Maiden <nmaiden@baaqmd.gov>
**Cc:** Jeff Weiss <JWeiss@airquality.org>; Felix Trujillo Jr. <FTrujillo@airquality.org>; Ali Othman <AOthman@airquality.org>
**Subject:** Bay Area AQMD's BACT Determination for Biogas Fired IC Engines



Hello Nicholas,

The Sac Metro Air District is evaluating a new BACT Determination for internal combustion, prime power, spark-ignited engines fueled by digester gas (or a blend of digester gas and natural gas), rated greater than 500 HP, and operating at a non-major stationary source (aka minor source). For the purposes of our BACT determination, we define "digester gas" as biogas produced from wastewater treatment facilities.

In our research, we found a Biogas Fired IC Engine (≥ 50 HP) BACT from your air district listed in the CARB BACT Clearinghouse. It would be a tremendous help to us if you or your staff could clarify a few details about this BACT:

- Does this BACT apply to prime power engines?
- Does "biogas" include biogas from dairy manure or just biogas produced from wastewater treatment facilities?
- Has Bay Area AQMD issued permits using these BACT standards for prime power engines operating at non-major sources?

Thank you in advance for your assistance.

**Joanne Chan**
Permitting
Engineering & Compliance Division
Sac Metro Air District
Direct: (279) 207-1173
JChan@airquality.org
www.AirQuality.org
@AQMD

SACRAMENTO METROPOLITAN
AIR QUALITY
MANAGEMENT DISTRICT

| BAY AREA AIR QUALITY MANAGEMENT DISTRICT |
| --- |
| Best Available Control Technology (BACT) Guideline |

**Source Category**

| Source: | IC Engine – Biogas Fired | Revision: | 1 |
| --- | --- | --- | --- |
| | | Document #: | 96.2.4 |
| Class: | ≥ 50 Hp Output | Date: | 5/30/2013 |

| Pollutant | BACT<br>1. Technologically Feasible/Cost Effective<br>2. Achieved in Practice | TYPICAL TECHNOLOGY |
| --- | --- | --- |
| POC | 1. 0.12 g/bhp-hr [a, c, e, f, g, k]<br>2. 0.16 g/bhp-hr [l, k] | 1. Gas Pre-Treatment (filtration, refrigeration & carbon adsorption) + Oxidation Catalyst [a, c, e, f, g, k]<br>2. Low POC Waste Gas or Gas Pre-Treatment or Gas Pre-Treatment + Oxidation Catalyst [l, k] |
| $NO_x$ | 1. n/s<br>2. 0.15 g/bhp-hr [a, c, d, e, f, g, i, j, l] | 1. Gas Pre-Treatment + Selective Catalytic Reduction (SCR) [f, g, l]<br>2. Gas Pre-Treatment + Selective Catalytic Reduction (SCR) [a, c, d, f, i, j, l] or NOxTech [e, i, j] |
| CO | 1. 0.89 g/bhp-hr [b, c, f]<br>2. 1.8 g/bhp-hr [a] | 1. Gas Pre-Treatment + Oxidation Catalyst [b, c, f]<br>2. Gas Pre-Treatment + Oxidation Catalyst [a] |
| $SO_2$ | 1. 100 ppmv of total sulfur in Biogas [c, g]<br>2. 150 ppmv of total sulfur in Biogas [a, b, h] | 1. Low Sulfur Biogas [c] or Gas Pre-Treatment with >80% $H_2S$ Removal [g]<br>2. Low Sulfur Biogas or Gas Pre-Treatment [a, b, h] |
| $PM_{10}$ | 1. 0.07 g/bhp-hr [b]<br>2. 0.10 g/bhp-hr [a, c] | 1. Gas Pre-Treatment (filtration and condensation) [b]<br>2. Gas Pre-Treatment [a, c] |
| NPOC | 1. n/d<br>2. n/s | 1. n/d<br>2. Same as POC |

**References and Notes for BACT Determination**

a. BAAQMD Application # 12649 (Ameresco Half Moon Bay, LLC)
b. BAAQMD Application # 23333 (Potrero Hills Energy Producers)
c. BAAQMD Application # 24388 (Zero Waste Energy)
d. San Joaquin Valley APCD: Ameresco Foothill and Forward Energy Projects
e. San Joaquin Valley APCD: Cambrian Energy Woodville, LLC Energy Projects
f. South Coast AQMD: Orange County Sanitation District Demonstration Project
g. Georgia Dept. of Natural Resources: MAS ASB Cogen, LLC CHP Facility
h. South Coast AQMD: Rule 431.1, amended 6/12/98.
i. South Coast AQMD: Rule 1110.2, Table III-B, amended 9/7/12.
j. San Joaquin Valley APCD: Rule 4702, Table 2, amended 8/18/11.
k. Formaldehyde is both a POC and a toxic air contaminant (TAC) and is typically the largest contributor to the health risks resulting from biogas fired engines. Oxidation catalysts typically achieve 50% or greater control of formaldehyde emissions. Use of an oxidation catalyst will satisfy the Regulation 2-5-301 TBACT requirement.
l. For SCR systems, ammonia emissions are typically limited to an exhaust concentration 10 ppmv of $NH_3$ at 15% $O_2$ or less. [c, f]

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**Joanne Chan**

| | |
|---|---|
| **From:** | William S. Sarraf <SarrafW@sbcapcd.org> |
| **Sent:** | Monday, May 20, 2024 12:23 PM |
| **To:** | Joanne Chan; engr |
| **Cc:** | Jeff Weiss; Felix Trujillo Jr.; Ali Othman |
| **Subject:** | RE: Santa Barbara County APCD's BACT Determination for Digester Gas Fired Engines |

***** THIS EMAIL ORIGINATED OUTSIDE AIRQUALITY.ORG *****

Hi Joanne,

The BACT Guideline 3.6 that was made was for a resource recovery project at the Tajiguas landfill that partially involved generating gas from the anerobic digestion of food and green waste and combustion of that gas in two 1,573 bhp Jenbacher GE spark ignited engines which produce power for onsite use. This project is located at a major source.

1. This BACT does apply to prime power engines

2. This BACT guideline does not set a horsepower threshold, however as I indicated above, the basis for the determination was the project at the Tajiguas landfill which proposed operating two 1,573 bhp digester fired engines for power generation.

3. Our determination does not differentiate between the type of digester gas, although the basis for the determination was digester gas generated from the anaerobic digestion of green and food waste at a landfill.

4. The only permit we have issued under this BACT determination was for the Tajiguas landfill, which is a major source. The new digester fired engines were part of a larger resource recover project at the landfill. Due to the size of the source test reports and permit, I have created a one-drive link were you can download a copy of the permit and initial source testing conducted on the two engines back in March 2022. Those documents can be found here:

   Tajiguas ADF Engine ST and Permit

   The current permit is in the process of being modified and that modification will be issued shortly. These modifications don't affect the engines subject to the BACT determination nor do they change the BACT determination.

Sincerely,

**William Sarraf**
Engineering Supervisor
Air Pollution Control District
Santa Barbara County

SarrafW@sbcapcd.org
805-979-8312

ourair.org @OurAirSBC

Sign Up for Air Alerts →

**From:** Joanne Chan <JChan@airquality.org>
**Sent:** Monday, May 20, 2024 11:04 AM
**To:** engr <engr@sbcapcd.org>; William S. Sarraf <SarrafW@sbcapcd.org>
**Cc:** Jeff Weiss <JWeiss@airquality.org>; Felix Trujillo Jr. <FTrujillo@airquality.org>; Ali Othman <AOthman@airquality.org>
**Subject:** Santa Barbara County APCD's BACT Determination for Digester Gas Fired Engines

Hello Santa Barbara County APCD engineering and BACT team,

The Sac Metro Air District is evaluating a new BACT Determination for internal combustion, prime power, spark-ignited engines fueled by digester gas (or a blend of digester gas and natural gas), rated greater than 500 HP, and operating at a non-major stationary source (aka minor source). For the purposes of our BACT determination, we define "digester gas" as biogas produced from wastewater treatment facilities.

In our research, we found a Digester Gas Fired Engine BACT from your air district (https://www.ourair.org/wp-content/uploads/BACT-Guideline-3.6.pdf) listed in the CARB BACT Clearinghouse. It would be a tremendous help to us if your staff could clarify a few details about this BACT:

- Does this BACT apply to prime power engines?
- Does this BACT apply to all engine HP greater than 50 HP?
- Does digester gas include biogas from dairy manure or just biogas produced from wastewater treatment facilities?
- Has Santa Barbara County APCD issued permits using these BACT standards for prime power engines operating at non-major sources?

Thank you in advance for your assistance.

**Joanne Chan**
Permitting
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SACRAMENTO METROPOLITAN AIR QUALITY MANAGEMENT DISTRICT

Santa Barbara County Air Pollution Control District

Our Vision Clean Air

# BEST AVAILABLE CONTROL TECHNOLOGY (BACT) GUIDELINE 3.6

| | |
|---|---|
| **Equipment Category:** | Digester Gas Fired Engines |
| **Revision:** | 1.1 |
| **Date:** | January 15, 2019 |

| Pollutant | BACT Requirement | BACT Technology | Performance Standard | AIP/TF |
|---|---|---|---|---|
| $NO_x$ | 1 | Gas pre-treatment (filtration, refrigeration, carbon adsorption, ammonia scrubbers), Selective catalytic reduction (SCR) with urea injection and ammonia slip of 5 ppmv @ 15% $O_2$ | 9 ppmv @ 15% $O_2$; 0.120 g/bhp-hr | AIP |
| ROC | 1 | Gas pre-treatment (filtration, refrigeration, carbon adsorption), oxidation catalyst | 26 ppmv @ 15% $O_2$ (as methane); 0.120 g/bhp-hr | AIP |
| CO | 1 | Gas pre-treatment (filtration, refrigeration, carbon adsorption), oxidation catalyst | 38 ppmv @ 15% $O_2$; 0.300 g/bhp-hr | AIP |
| $SO_x$, PM, $PM_{10}$, $PM_{2.5}$ | 1 | Digester gas treated using a continuously operating sulfur removal system | Case-by-case | AIP |
| Multiple Pollutants | 1 | Engine Inspection and Maintenance Plan | N/A | AIP |

Notes:
1. $NO_x$ means oxides of nitrogen (as $NO_2$) and $SO_x$ means oxides of sulfur (as $SO_2$).
2. AIP means Achieved in Practice. TF means Technologically Feasible.
3. BACT is the most stringent control technique for the emissions unit and equipment category that is either achieved in practice or technologically feasible/cost effective.
4. BACT determinations are subject to periodic updates without advanced notice.

# Attachment D

## Unit Conversions for Pollutant Emission Standards

## Calculating the Emission Factor (from ppm to g/hp-hr) --- Digester Gas engine

Conversion Factor: 453.6 g / lb

Conversion Factor: 453.6 mol / lb-mol

Conversion Factor: 1 lb / lb-mol = 1 g / mol (because 1 lb-mol is 453.6 mol, which is the same ratio between 1 lb and 1 gram).

Molar Volume of Exhaust: 385.3 scf / mol of exhaust (scf / lb-mol of exhaust) based on Ideal Gas Law for a gas at standard conditions of 68°F and 1 ATM

Molecular Weight of NOx (based on NO2): 46.01 g NOx / mol of exhaust (lb NOx / lb-mol of exhaust)

Molecular Weight of CO: 28.01 g CO / mol of exhaust (lb CO / lb-mol of exhaust)

Molecular Weight of VOC (based on CH4 methane): 16.04 g VOC / mol of exhaust (lb VOC / lb-mol of exhaust)

Molecular Weight of NH3 (ammonia slip): 17.03 g NH3 / mol of exhaust (lb NH3 / lb-mol of exhaust)

Molecular Weight of CH2O (formaldehyde): 30.03 g CH2O / mol of exhaust (lb CH2O / lb-mol of exhaust)

Fuel F-Factor (Digester Gas): 8,710 dscf / MMBtu Assumed the same as Natural Gas

HHV (Digester Gas): 620 Btu / scf Source: Section 3 of SacSewer's BioGen Project Proposal - Digester Gas Engines

Brake-specific fuel consumption (BSFC) - Digester Gas: 5,542 Btu / hp-hr Source: SacSewer's BioGen Project Application for 4 CoGen Engines fired on digester gas or a blend of digester gas and natural gas (Jenbacher model J616GS-J325 Technical Data)

Average % atmospheric oxygen at ground-level: 20.9 % $O_2$

Adjusted % oxygen for the corresponding PPM: 15 % $O_2$

| Pollutant Concentration | | | | Emission Factor Calculated from Pollutant Concentration | |
|---|---|---|---|---|---|
| NOx | 11 | ppmv @ 15% $O_2$ | → → → | 0.10 | g / hp-hr |
| CO | 250 | ppmv @ 15% $O_2$ | → → → | 1.41 | g / hp-hr |
| VOC | 30 | ppmv @ 15% $O_2$ | → → → | 0.10 | g / hp-hr |
| NH3 | 10 | ppmv @ 15% $O_2$ | → → → | 0.03 | g / hp-hr |
| CH2O | 70 | ppmv @ 15% $O_2$ | → → → | 0.42 | g / hp-hr |

***Emission Standard Verification***

**ppmv ↔ g/bhp-hr**

**ppmv** = **($V_p$ / $V_e$)** x (10^6) = concentration of pollutant in exhaust by volume (dry)

where: **$V_p$** = volume of pollutant (dscf/hr) = **EF** x **BHP** x (1/**CF**) x (1/**MWp**) x **mv**

**EF** = pollutant emission factor (g/bhp-hr)

**BHP** = maximum continuous rated engine brake horsepower (bhp)

**CF** = conversion factor (453.6 g/lb)

**$MW_p$** = molecular weight of pollutant (lb/lb-mol)

**mv** = molar volume (385.3 scf/lb-mol @ std conditions temp of 60ºF)

where: **$V_e$** = volume of exhaust (dscf/hr) = **$F_D$** x **EAC** x **BSFC** x **BHP** x [1/(10^6)]

**$F_D$** = Natural Gas F-factor of exhaust volume at 0% $O_2$ and 60ºF (8710 dscf/MMBtu)

**EAC** = excess air correction from 0% $O_2$ to 15% $O_2$ [20.9/(20.9-15) = 3.5424]

**BSFC** = engine brake-specific fuel consumption (fired on digester gas 5542 Btu/hp-hr)

**BHP** = maximum continuous rated engine brake horsepower (bhp)

**ppmv** = { [ **EF** x **BHP** x (1/**CF**) x (1/**$MW_p$**) x **mv** ] / [ **$F_D$** x **EAC** x **BSFC** x **BHP** x 1/(10^6) ] } x (10^6)

**ppmv** = { [ **EF** x (1/**CF**) x (1/**$MW_p$**) x **mv** ] / [ **$F_D$** x **EAC** x **BSFC** ] } x (10^12)

[ **ppmvd** / (10^12) ] x [ **$F_D$** x **EAC** x **BSFC** ] x [ **CF** x **$MW_p$** / **mv** ] = **EF**

***Emission Factor (g/hp-hr)***

**EF** = **[ ppmvd** / (10^12)] x **$F_D$** x **EAC** x **BSFC** x **CF** x **$MW_p$** / **mv**

= **[ ppmvd** / (10^12)] x [digester gas F-factor] x [adjusted Oxygen] x **BSFC** x [conversion factor for g/lb] x [molecular weight of NH3] / [molar volume of exhaust]

**example with 20ppm NH3** = [**20** ppm / (10^12)] x (8710 dscf / MMBtu) x [ 20.9 / (20.9-15) ] x **(5542 Btu/hp-hr)** x (453.6 g/lb) x [(**17.03 lb NH3**/lb-mol of exhaust) / (385.3 scf/lb-mol of exhaust)]

= **0.034**

**Comments:**

Conversions for the emission standard verification (ppmv to g/bhp-hr) are calculated based on the Santa Barbara County APCD's Piston IC Engine Technical Reference Document (dated 11/01/2002), formula in Section II.B7. Pursuant to Section III.A1.(d), SOx emission factors should be based on mass emission calculations (such as the formula found in Section II.A5 - Fuel Sulfur Mass Balance for Gaseous Fuels).

# Attachment E

## SCAQMD's Pilot Studies

**demonstrated that waste gas-fired engines could achieve Rule 1110.2 NOx emission standard of 11 ppmvd @ 15% $O_2$ using an SCR system or equivalent technology, and also demonstrated it was not technologically feasible to achieve the DG NOx standard-equivalent of 2.5 ppmvd @ 15% $O_2$**

**Orange County Sanitation District**
10844 Ellis Avenue • Fountain Valley CA 92708-7018

# Retrofit Digester Gas Engine with Fuel Gas Clean-up and Exhaust Emission Control Technology

South Coast Air Quality Management District Contract #10114

# Pilot Testing of Emission Control System Plant 1 Engine 1

Orange County Sanitation District Project No. J-79

FINAL REPORT

July 2011

Report Prepared By:

**Malcolm Pirnie, The Water Division of ARCADIS**

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The Water Division of ARCADIS

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## Glossary of Terms

| **Acronym** | **Definition** |
|---|---|
| ARB | Air Resources Board |
| AQMD | Air Quality Management District |
| BACT | Best Available Control Technology |
| bhp | Brake horse power |
| CEMS | Continuous emissions monitoring systems |
| CI | Compression Ignition |
| CO | Carbon monoxide |
| $CO_2$ | Carbon dioxide |
| Cpsi | Cells per square inch |
| °C | Degrees Centigrade |
| °F | Degrees Fahrenheit |
| DG | Digester Gas |
| DGCS | Digester Gas Cleaning System |
| EPA | Environmental Protection Agency |
| FTIR | Fourier Transform Infrared |
| GC/MS | Gas chromatography-mass spectrometry |
| $H_2S$ | Hydrogen sulfide |
| HHV | Higher Heating Value |
| HI | Hazard Index |
| hp | Horse power |
| HRU | Heat Recovery Unit |
| IC | Internal Combustion |
| in. w.c. | Inches water column |
| KW | Kilowatt |
| MDL | Method Detection Limit |
| MMscf | Million standard cubic feet |
| MW | Megawatts |
| $N_2$ | Nitrogen |
| NG | Natural Gas |
| NMHC | Non-methane hydrocarbons |
| NMNEOC | Non-methane non-ethane organic compounds |
| $NO_2$ | Nitrogen dioxide |
| $NO_x$ | Nitrogen oxides |
| $O_2$ | Oxygen |
| OCSD | Orange County Sanitation District |
| PEMS | Parametric Emission Monitoring System |
| PM | Particulate matter |
| ppbv | Parts per billion by volume |
| ppm | Parts per million |
| ppmv | Parts per million by volume |
| psig | Pounds per square inch gage |
| RPM, rpm | Revolutions per minute |
| SCAQMD | South Coast Air Quality Management District |
| SCAT | Synthetic gas matrix catalyst activity test |
| scfm | Standard cubic feet per minute |

| **Acronym** | **Definition** |
|---|---|
| SI | Spark-ignited |
| VOCs | Volatile organic compounds |
| XRF | X-ray fluorescence |

## Acknowledgements

This pilot study could not have been accomplished without the support and cooperation of the following people (listed in alphabetical order), as well as numerous others who contributed to the performance of the project.

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- Trimbak Vohra

<u>Malcolm Pirnie, Inc.</u>

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- Daniel Stepner

# Executive Summary

The Orange County Sanitation District (OCSD) owns and operates two wastewater treatment plants in Orange County, California, Reclamation Plant No. 1 (Plant 1) in Fountain Valley and Treatment Plant No. 2 (Plant 2) in Huntington Beach. Each plant operates a Central Power Generation System (CGS) to produce electrical power for the plant operations using large digester gas-fired internal combustion (IC) engines. Plant 1 has three (3) 2.5-megawatt (MW) internal combustion (IC) engines and Plant 2 has five (5) 3-MW IC engines, fueled primarily by digester gas (a biogas) and supplemented by small amounts of natural gas.

Plants 1 and 2 are within the jurisdiction of the South Coast Air Quality Management District (SCAQMD). SCAQMD has established regulations aimed at reducing and controlling air emissions from combustion sources, such as the engines at the plant CGS, including Rule 1110.2 *Emissions from Gaseous and Liquid-fueled Internal Combustion Engines*. In February 2008, SCAQMD amended Rule 1110.2, lowering the emission limits for nitrogen oxides (NOx), volatile organic compounds (VOCs), and carbon monoxide (CO) for IC engines. The amended rule also requires biogas-fueled engines to meet new lower NOx, CO, and VOC emission limits effective July 2012.

In April 2008, OCSD engaged Malcolm Pirnie to conduct an emission reduction technology evaluation of the CGS engines in order to identify technologies for reducing NOx, CO, and VOC emissions to meet the new Rule 1110.2 emission limits, including combustion modification and post-combustion control. After a detailed review of different technologies, the post-combustion technology of catalytic oxidizer/selective catalytic reduction (Cat Ox/SCR) system with digester gas cleaning system (DGCS) using carbon adsorption was recommended as the technology with the most potential for meeting the future Rule 1110.2 emission limits. OCSD then embarked on a full-scale pilot study of the recommended technology on Engine 1 at Plant 1 to evaluate if the future amended Rule 1110.2 limits can be met for their digester gas-fired IC engines. Because SCAQMD recognized that the future emission limits in amended Rule 1110.2 were “technology-forcing,” the Governing Board directed staff to conduct a technology assessment to determine if cost-effective and commercially available technologies exist that can achieve these new lower emission limits. SCAQMD issued a grant to OCSD in 2009 (*SCAQMD Contract #10114*) to support the pilot test study at Plant 1 Engine 1, and the operation of the pilot study was granted a Permit to Construct/Operate for an Experimental Research Project by SCAQMD (Application Number 497717) in November 2009. The construction and installation of the pilot study equipment commenced in October 2009; the pilot study testing officially began on April 1, 2010 and officially ended on March 31, 2011.

Under the pilot study, Engine 1 at Plant 1 was equipped with a catalytic oxidizer to remove CO and VOCs, followed by an SCR system with urea injection to remove NOx (both systems supplied by Johnson Matthey). Due to space limitations at Plant 1, the catalytic oxidizer and SCR systems were mounted on a platform 14 feet above an onsite access road. Engine 1 is fueled primarily by digester gas, supplemented by natural gas. Digester gas contains low concentrations of siloxanes and other compounds which convert to sand-like particulate during combustion (silica) that contribute to rapid degradation of engines, gas turbines, and boilers, along with increased maintenance requirements. In addition, the silica also adheres to the catalyst media of the post-combustion control equipment. Therefore, a digester gas cleaning system (DGCS) was installed (supplied by Applied Filter Technology) to remove these contaminants from the digester gas before it was combusted in Engine 1. The potential for carbon media breakthrough was routinely monitored for using Draeger® tubes to measure hydrogen sulfide ($H_2S$) concentrations. Samples of the digester gas before and after the DGCS were also sent for laboratory analysis to measure for siloxane, $H_2S$, and VOCs that could indicate media breakthrough. During the study, inlet and outlet concentrations of CO, NOx, and VOCs were measured to determine the potential reductions in emissions due to the Cat Ox/SCR system. Sampling methods included:

- CO: Portable analyzer, SCAQMD Method 100.1
- VOCs: SCAQMD Methods 25.1/25.3
- NOx: Portable analyzer, SCAQMD Method 100.1
- Aldehydes: Modified CARB Method 430, SCAQMD Method 323 (formaldehyde)
- Ammonia slip (free ammonia): Modified SCAQMD Method 207.1 and Draeger® tubes

In addition, data from the OCSD's continuous emissions monitoring system (CEMS) was collected at the engine exhaust (inlet to the Cat Ox system) for NOx and at the stack exhaust for NOx, CO, and $O_2$. All CEMS data is based on 15-minute averages. Sampling was also performed for formaldehyde, acetaldehyde, and acrolein as required by the Experimental Research Project permit. In addition, ammonia levels in the stack exhaust were also measured to quantify potential ammonia slip, a result of the urea injection used in the SCR system. The overall conclusions of the pilot study are as follows:

1. The average NOx concentration at the stack exhaust after the pilot study controls was approximately 7 ppmv, below the 11 ppmv required under amended Rule 1110.2. The lowest NOx stack exhaust concentration met consistently under all valid conditions was 16 ppmv. While there were some periods (i.e., 15-minute block averages) where the NOx stack exhaust concentration was above 11 ppmv, after screening these periods, 181 periods out of 21,285 total operating periods (approximately 5,321 hours) remained as valid NOx excursions above the new Rule

1110.2 limit. These periods occurred during 61 separate events and accounted for less than 0.9% of the total measurement periods during the pilot study. Excursions were considered valid when they occurred during periods/events when the percentage of natural gas increased to above 5% of the fuel blend, when engine loads exceeded the loads mapped during the SCR system commissioning, or during periods/events not attributable to engine start-up or operational /system adjustments. An implication of these remaining periods are that the 11 ppmv limit is too conservative an emission limit, and may warrant further evaluation and potential increase and/or a specified percentage of allowable excursions.

2. SCR systems similar to the Johnson Matthey® system used in the present pilot study are commercially available for combustion units fueled by single component fuels, such as natural gas. Although the SCR system did not consistently meet the 11 ppmv limit with the digester gas/natural gas fuel blend in the pilot study, it did demonstrate a significant reduction in NOx emissions.
3. The free ammonia concentration was below 0.5 ppmv during all testing events using either SCAQMD compliance method 207.1, and below the Method Detection Limit (MDL) using Draeger® tubes.
4. The maximum CO concentration at the stack exhaust using the CEMS data was 42.2 ppmv, well below the amended Rule 1110.2 emission limit of 250 ppmv.
5. The maximum VOC concentration at the stack exhaust was found to be 4.95 ppmv, and was consistently well below the 30 ppmv limit in amended Rule 1110.2.
6. The use of the combined Cat Ox/SCR system in the pilot study resulted in significant reductions in CO, VOC, and NOx.
7. The DGCS system, in general, removed siloxanes from the digester gas to below Method Detection Limit (MDL) levels and significantly reduced sulfur compounds and VOCs successfully reducing catalyst masking which should lead to extended catalyst life. Additional benefits of the contaminant removal were significant improvements in engine maintenance requirements and lower O&M costs.
8. The total capitals cost to design, procure, and install a digester gas cleaning vessel to clean all the digester gas to the three Plant 1 engines, and a Cat Ox/SCR system with auxiliary equipment for Engine 1 is estimated to be $2,300,000. The annual operations and maintenance (O&M) cost for these systems at Plant 1 is approximately $59,000. Assuming a 20-year lifespan, the total annualized cost (capital cost plus O&M) for the DGCS and Cat Ox/SCR systems for Plant 1 Engine 1 is $227,000.
9. The cost effectiveness analysis (based on dollars per ton of NOx, VOC, and CO emissions reduced) was developed for two scenarios: Scenario 1 assumed that the uncontrolled emissions were developed based on current permit limits (i.e., 45 ppmv, 209 ppmv, and 2,000 ppmv, respectively), and Scenario 2 assumed that the uncontrolled emissions were developed based on the results from the 2011 Annual Compliance Test for Engines 2 and 3. Both scenarios assumed that the controlled emissions were based on the Rule 1110.2 limits of 11 ppmv for NOx and 30 ppmv

for VOCs, and the pilot testing results of 15 ppmv for CO. Under these assumptions, the cost effectiveness for Scenarios 1 and 2 is $7,987 and $17,585, respectively, per ton of NOx plus VOCs reduced. The cost effectiveness for Scenarios 1 and 2 is $636 and $3,546, respectively, per ton of CO reduced. Note that the cost effectiveness for CO is conservative since the annualized cost is based on the entire system including the SCR and urea injection system. The annualized cost and emissions reduced calculations were based on operating each engine for a maximum of 6,000 hours per year.

# 1. Project Background and Objectives

## 1.1. Background

The Orange County Sanitation District (OCSD) owns and operates two (2) wastewater treatment plants that serve 21 cities and three special districts in the central and northwest Orange County, California, Reclamation Plant No. 1 (Plant 1) in Fountain Valley and Treatment Plant No. 2 (Plant 2) in Huntington Beach. In addition to the wastewater treatment processes, each plant operates a Central Power Generation System (CGS) to produce electrical power for the plant operations using large digester gas-fired internal combustion (IC) engines. Plant 1 has three (3) 2.5 megawatt (MW) internal combustion (IC) engines and Plant 2 has five (5) 3 MW IC engines, fueled primarily by digester gas (a biogas) and supplemented by small amounts of natural gas. Biogas, a by-product of the anaerobic digestion of wastewater solids, is classified as a renewable fuel, and the combustion of the biogas in the IC engines provides a beneficial reuse of a waste product.

Plants 1 and 2 are within the jurisdiction of the South Coast Air Quality Management District (SCAQMD). SCAQMD has established regulations aimed at reducing and controlling air toxic emissions from combustion sources, such as the engines at the plant CGS, including Rules 1110.2, 1401 and 1402. Under Contract J-79 Air Toxics Emission Reduction Strategic Plan (2003), Malcolm Pirnie was retained by the OCSD to perform an evaluation of regulations addressing air toxic requirements under the rules. Malcolm Pirnie prepared an emission reduction study/air toxics strategic plan for the OCSD to comply with the NOx emission limit under Rule 1110.2 for IC engines. The study also addressed acceptable risk levels from Plant 1 and Plant 2 to comply with Rules 1401 and Rule 1402 (*Air Toxic Emission Reduction Strategic Plan* (Malcolm Pirnie, 2004) and *2012 Air Toxic Emission Reduction Strategic Plan* (Malcolm Pirnie, 2006)). The study identified the formaldehyde emissions from the CGS engines as a significant contributor to the overall risk levels, and also identified a catalytic oxidizer system with a digester gas cleaning system (DGCS) as a viable control technology to reduce the formaldehyde emissions from the digester gas-fired IC engines. This system was evaluated in a full-scale pilot study of a catalytic oxidizer system on Engine 3 at Plant 2 (*Catalytic Oxidizer Pilot Study* (Malcolm Pirnie, 2007)).

A catalytic oxidizer system is one of the most promising technologies for controlling carbon monoxide (CO) and volatile organic compounds (VOC) emissions from combustion units burning natural gas. However, fouling or rapid performance degradation of the catalytic oxidizers has been an issue for engines burning digester gas due to contaminants in the digester gas, such as volatile methyl-siloxanes and sulfurous compounds that tend to foul the catalytic oxidizers. Therefore, the use of a digester gas cleaning system to prevent the contaminants in the digester gas from fouling and/or masking the catalyst was also evaluated.

In February 2008, SCAQMD further amended Rule 1110.2 to reduce emission limits for nitrogen oxides (NOx), VOCs, and CO, and also to improve/enhance monitoring, recordkeeping and reporting requirements for IC engines. Biogas engines were given until July 2012 to meet new lower emission limits. Malcolm Pirnie conducted an emission reduction technology evaluation of the CGS engines and identified several technologies for reducing NOx, CO, and VOC emissions, including combustion modification and post-combustion control (*Feasibility Study for a Technology Evaluation for Compliance with Amendments to SCAQMD Rule 1110.2 – Emissions from Gaseous and Liquid-fueled Internal Combustion Engines* (Malcolm Pirnie, 2008)). After a detailed review of the different technologies, the post-combustion technology of catalytic oxidizer/selective catalytic reduction (Cat Ox/SCR) system with DGCS using carbon adsorption was recommended as the technology with the most potential for meeting the future Rule 1110.2 emission limits.

In 2009, OCSD embarked on a pilot study of this recommended technology on Engine 1 at Plant 1 to evaluate if the future Rule 1110.2 limit can be met for their biogas-fired IC engines. Design of the pilot system included an SCR system for NOx emission reduction, an oxidation catalyst unit for CO and VOC reduction (including formaldehyde), and a DGCS upstream from the IC engines for removal of siloxanes to prevent fouling of the catalysts. Additional benefits of the DGCS include the removal of total reduced sulfur and total volatile organic compounds. To supplement and support this study, SCAQMD issued a grant to OCSD (SCAQMD Contract #10114, 2009) for this pilot test study, and will be evaluating the data collected as part of their technology assessment of the feasibility of biogas engines achieving the future Rule 1110.2 emission limits for biogas-fired engines. The operation of the pilot study was granted a Permit to Construct/Operate for an Experimental Research Project by SCAQMD (Application Number 497717) (Appendix A-1).

## 1.2. SCAQMD Rule 1110.2

The IC engines at OCSD are subject to Rules 1110.2. Rule 1110.2 provides emission limits and monitoring requirements for all stationary and portable engines over 50 brake-horsepower (bhp). Rule 1110.2 (*Emissions from Gaseous- and Liquid- Fueled Engines*) was promulgated to reduce the NOx, CO and VOC emissions from engines over 50 bhp. On February 1, 2008, Rule 1110.2 was amended in order to achieve further emissions reductions from stationary engines based on the cleanest available technologies. Under the February 2008 amendments to Rule 1110.2 shown below, more stringent NOx, CO, and VOC limits were adopted, to become effective for biogas-fueled engines in July 2012 provided a technology assessment confirms that the limits below are achievable.

- NOx limit was lowered from 36 ppm (or ~ 45 ppm*) to 11 ppm at 15% $O_2$.
- VOC limit was lowered from 250 ppm* to 30 ppm at 15% $O_2$.
- CO limit was lowered from 2,000 ppm to 250 ppm at 15% $O_2$.

* Existing limits allow for an alternative emission limit for OCSD engines based on the engine efficiency correction factor.

The rule allows for some exemptions, including an exemption during engine start-up, to allow for sufficient operating temperatures to be reached for proper operation of the emission control equipment. The start-up period is limited to 30 minutes unless a longer period is approved for a specific engine by the Executive Officer and is made a condition of the engine permit.

## 1.3. Objectives

Because the future Rule 1110.2 emission limits shown above are "technology-forcing," the SCAQMD Governing Board directed staff to conduct a technology assessment to determine if cost-effective and commercial technologies are available to achieve their limits. This pilot study will be used by SCAQMD as part of that technology assessment to evaluate the ability of the biogas-fueled engines at OCSD wastewater treatment plants to meet these future limits.

The objective of this study is to evaluate the effectiveness of a Cat Ox/SCR system with a DGCS as a post-combustion emissions control technology for an IC engine operating on biogas at a wastewater treatment plant. The data collected will be evaluated as part of the technology assessment study for the 2012 biogas engine emission limits under amended Rule 1110.2. Data were gathered on engine performance and emission reductions. Data were also gathered to obtain information for use in full-scale design (e.g., back pressure, impact on heat recovery unit (HRU)), to assess the performance of the DGCS (e.g., siloxane removal, media life), and to determine the economic feasibility of operating the Cat Ox/SCR system and the DGCS.

## 1.4. Report Organization

This report is organized into the following sections:

- Executive Summary
- Section 1. Project Background and Objectives
- Section 2. Pilot Study Work Plan
- Section 3. Results and Discussion
- Section 4. Cost Effectiveness Analysis
- Section 5. Conclusions and Recommendations

- Appendices

# 2. Pilot Study Work Plan

## 2.1. General Description

The engines at the CGS at both the Fountain Valley Reclamation Plant 1 and Huntington Beach Treatment Plant 2 are lean-burn, spark-ignited IC engines, and have been permitted to operate by SCAQMD. Plant 1 has three (3) 2,500 kilowatts (KW) units, while Plant 2 has five (5) 3,000 KW units. The engines are of conventional four-stroke cycle stationary Vee engine construction. They utilize spark-ignited pre-chamber technology to achieve extremely low NOx emissions. These electrical power generation stations utilize state-of-the-art low emission, spark-ignited, reciprocating engines fueled by digester gas and/or natural gas to drive generators. The engine generators normally operate in parallel with the grid, providing electrical loads at both plants. Excess power at Plant 2 is exported to the local utility. Waste heat energy in the cooling systems and exhaust are extracted and utilized for process heating through heat recovery units on each engine. Plant 2 has the capability to produce additional electrical energy with waste heat energy through use of a steam turbine-generator. Typically, at any given time one unit is down at Plant 1 and two units are down at Plant 2 for maintenance while the remaining units operate over a range of 60-120% load. Once placed on line, an engine will operate approximately 1,000-2,000 hours before being shut down for routine maintenance.

At Plant 1, each of the three IC engines are rated at 3,471 bhp, and each engine can produce up to 2.5 MW of electricity. This pilot study was conducted on Engine 1 at Plant 1 (see Figure 2-1). Details of the three Plant 1 engines, including Engine 1 are shown in Table 2-1.

Based upon a carefully designed series of studies performed for OCSD to meet existing and emerging regulatory standards, the full-scale pilot study of Engine 1 at Plant 1 included a DGCS using carbon media for removal of siloxanes and other harmful contaminants from the digester gas, and post-combustion control technology using a catalytic oxidizer system to reduce emissions of CO and VOCs, and SCR technology with urea injection for controlling of NOx emissions. The engine is equipped with continuous emissions monitoring system (CEMS) at the engine exhaust for measuring NOx concentration entering the Cat Ox/SCR system, and at the stack for measuring NOx, CO, and oxygen ($O_2$) concentrations after the Cat Ox/SCR system. Figure 2-2 and Appendix A-2 shows a schematic of the overall system.

Construction of the pilot study was initiated in October 2009. During the design and construction for the pilot study, two other projects were also in progress at Plant 1:

- J-79-1 Central Generation Automation. During this project, the engine control systems (ECS) for the CGS at both plants were replaced. The existing ECS at both facilities were no longer being manufactured and parts replacement was not reliable. The new systems provide automatic load management capability, as well as an emissions monitoring feedback signal for exhaust emissions control.

- J-79-1A Continuous Emissions Monitoring Systems. Installation of a CEMS at the stack outlets of the CGS engines at both plants and NOx inlet analyzers.

Prior to the start of the full-scale pilot study, both J-79-1 and J-79-1A projects were completed at Plant 1 Engine 1 before the pilot system commenced operation in April 2010 and initial performance testing was performed on both the DGCS and Cat Ox/SCR system.

## 2.2. Digester Gas Cleaning System

Digester gas is generated during the anaerobic digestion of the sewage sludge produced during the wastewater treatment process. This biogas contains contaminants such as hydrogen sulfides ($H_2S$), VOCs, and low concentrations of volatile siloxane compounds. Siloxane is a compound that is found in numerous consumer personal products and thus enters the wastewater treatment system. During combustion, the siloxanes convert to silica, sand-like particulate that deposit on the surfaces of combustion equipment contributing to a rapid degradation of engines, gas turbines, and boilers, along with increased maintenance requirements. In addition, the silica also adheres to the catalyst media of any post-combustion control equipment. These deposits can cause masking of the catalyst sites that significantly reduces the effectiveness of the catalyst. Based upon the pilot testing performed at Plant 2 (Malcolm Pirnie, 2008), the DGCS was shown to be successful in removing contaminants such as siloxanes, $H_2S$, and VOCs from the digester gas, and extending the catalyst performance life comparable to an IC engine combusting natural gas. In addition, the use of the DGCS resulted in a significant reduction in operations and maintenance (O&M) costs for the CGS engines.

### 2.2.1. DGCS Technology and Equipment

In order to minimize the masking effect from the siloxanes and sulfurous compounds, and prevent the deterioration of the post-combustion Cat Ox/SCR system installed for the pilot study, the digester gas was scrubbed to remove these contaminants prior to combustion. A DGCS (SAG™) supplied by Applied Filter Technology, Inc. (AFT) and consisting of a single carbon media vessel was installed at Plant 1. The SAG™ process was developed to remove siloxanes and other contaminants considered harmful to power generation equipment including engines, gas turbines, fuel cells and boilers. The media also treats VOCs, $H_2S$, and other sulfides. The vessel contains three layers of specialized graphite-based molecular sieves, which are small to large black pellets or spheres, capable of removing, through adsorption, the siloxanes from the biogas. The sieve types and layer depths (and the resulting vessel size) are determined by gas analysis to confirm system performance parameters. The biogas enters the SAG™ vessel at the top and proceeds down through the layers of sieves, exiting through flanged septa connected to a manifold header. Each layer removes a specific type of contaminant and, in turn, protects the layer following it by removing contaminants that can foul it. The SAG™ siloxane media is a loose pellet form of polymorphous graphite carbon-based media specifically designed for removal of siloxanes in methane, and can be disposed of as a non-hazardous waste at a local approved site. Following system start-up, the vessel is allowed to process the biogas until there is breakthrough. In the present pilot study, the potential for media breakthrough was conservatively determined using $H_2S$ as a marker. Once the potential for breakthrough is determined, the media is scheduled for change out. The vessel is then taken out of service, the media is replaced, and the vessel is returned to service.

The SAG™ unit used in the pilot study was a single stage, 7.5 ft diameter by 8 ft straight -sided dished downflow carbon steel filter unit. The unit contained 9,900 lbs of SAG™ three-stage media for siloxane removal. It includes interior high build epoxy coating and corrosion allowance vessel plate thickness. The DGCS system was sized and designed such that it could be used to clean all the digester gas produced at Plant 1. The DGCS was designed for the conditions presented in Table 2-2.

The DGCS was located along the south side of the Gas Compressor Building. Figure 2-3 shows a photograph of the DGCS at the Plant 1.

### 2.2.2. DGCS Measurement and Monitoring Methods

One objective of this pilot study was to assess the performance of the DGCS with respect to the removal of siloxanes and other contaminants, along with the life of the removal media. Based on the pilot testing performed at Plant 2 Engine 3, the DGCS proved successful in removing contaminants from the digester gas. The catalyst at Plant 2 Engine 3 fouled rapidly after combustion of uncleaned digester gas. Catalyst performance with the DGCS was comparable to that of a catalyst installed on the exhaust of an IC engine operating on natural gas.

Testing was performed to determine if the equipment met the design specifications. Two sampling methods are commonly used for measuring siloxanes: gas chromatography-mass spectrometry (GC/MS) and the wet chemistry method. Digester gas analyzed using GC/MS can be collected using either Tedlar® bags or canisters. The wet chemistry method requires samples to be collected using methanol impingers over a two to four hour sampling period, and then sent to a lab for analysis. After discussions with several certified laboratories, and review of several published papers, both methods were found to have merit; however, the collection of the samples using Tedlar® bags for measurement by GC/MS provided the most flexibility for minimum sampling time and equipment required. In the initial performance testing of the gas cleaning system, samples were collected using Tedlar® bags, canister, and methanol impinger methods at the digester gas inlet location at the same time, during the same day, and the analytical results were compared to determine the most appropriate method for analyzing performance breakthrough. During the initial test, individual measurements of inlet total siloxane, consisting of, hexamethylcyclotrisiloxane (D3), octamethylcyclotetrasiloxane (D4), decamethylcyclopentasiloxane (D5), hexamethyldisiloxane (L2), octamethyltrisiloxane (L3), and any other siloxane compounds identifiable according to the test method, were recorded.

For the sampling performed using Tedlar® bags at the DGCS inlet, the samples were collected and sent to a certified laboratory for the analysis of speciated siloxanes using TO-14/15, speciated VOCs using TO-15, total reduced sulfides using EPA 1023 Method 16B, or ASTM Procedure D-5504 GC/SCD, and the overall gas components and quality (% $CH_4$, % $CO_2$, % $N_2$, heating value using) using EPA Method 3C. One sample was also collected at the DGCS outlet to confirm that the DGCS met performance standards for all siloxanes to be measured as non-detect (i.e., below Method Detection Limit, MDL).

Samples were also collected in SUMMA® canisters at the DGCS inlet and sent to a certified laboratory for analysis of speciated siloxanes. In addition, speciated VOCs were analyzed using TO-15, total reduced sulfides were analyzed using ASTM D-5504, and overall gas components and quality (% $CH_4$, % $CO_2$, % $N_2$, heating value) was analyzed using ASTM D-1946.

The wet chemistry method was used at the DGCS inlet. During the test, the digester gas sample was collected using methanol impingers over a 4-hour period, and the samples were sent to the laboratory for individual measurements of inlet total siloxane.

Hydrogen sulfide testing was conducted weekly using Draeger® tubes. The $H_2S$ concentration was used as an indicator that the media was nearing saturation. Breakthrough itself was determined to occur when the total siloxane concentration at the outlet of the carbon adsorber was above the MDL or when the $H_2S$ concentration reached 15 ppm. Originally, the monitoring plan recommended by the vendor, AFT, was to use an $H_2S$ concentration threshold of 5 ppm at the outlet to trigger siloxane and siloxane compound testing every week until breakthrough occurred. However, a more conservative approach for media saturation was used for the pilot study. Saturation and media replacement was triggered when measurable $H_2S$ levels (generally around 1 ppm) were found using the Draeger® tube readings. The procedures used for taking the Draeger® tube measurements are shown in the Monitoring Test Procedure in the CD attached to this report. OCSD staff also performed routine sampling of the digester gas for $H_2S$ (Draeger® tubes), sampling for reduced sulfides (SCAQMD Method 307-91), and sampling for speciated VOCs (TO-15).

### 2.2.3. Selection of DGCS Sampling Method

Details of the DGCS performance test are presented in a Technical Memorandum (Malcolm Pirnie, May 5, 2010) found in Appendix A-3. Table 2-3 summarizes the results of the comparison of siloxane sampling methods.

As shown in the summary of the results shown in the table, the Tedlar® bag sampling method detected the highest level of total siloxane. In addition, the Tedlar® bag sampling method provided the most flexibility for minimum sampling time and equipment required. Based on these criteria, the Tedlar® bag method was chosen as the sampling method for the digester gas sampling for siloxanes.

## 2.3. Cat Ox/SCR System

Based on the results of the Catalytic Oxidizer Study on Plant 2 Engine 3 (Malcolm Pirnie, 2007) and the Feasibility Study (Malcolm Pirnie, 2008), the combination of a catalytic oxidizer followed by selective catalytic reduction equipment with urea injection provided by Johnson Matthey (JM) was selected for the pilot study.

Catalytic oxidation is a post-combustion control technology which has been commercially proven to reduce CO, VOCs and air toxics, including formaldehyde and acrolein, from engines burning natural gas. There is, however, limited performance data for an engine fired with digester gas, either with or without a gas cleaning system. The digester gas, which is generated during the biological consumption of solids that are collected during the wastewater treatment process, contains low but detrimental concentrations of siloxane compounds, which convert to silica during combustions and deposit on the surfaces of post-combustion equipment, including catalyst media. This fouling of the catalyst, or catalyst masking, significantly reduces the effectiveness of the catalyst. In order to minimize this masking effect, the digester gas can be pre-cleaned to remove these siloxanes prior to combustion.

The Johnson Matthey catalyst elements are manufactured in a “block” form. The catalyst block substrate is made from stainless steel foil that is retained by a stainless steel frame. This structure undergoes a proprietary coating process in which the foil is chemically treated to increase surface area. Active platinum group metal catalysts are then applied. The coating, catalyst composition, and honeycomb pore size were designed by Johnson Matthey to provide optimum durability and pollutant removal efficiency for the specified operating environment.

In the SCR system, the exhaust enters a mixing tube where a stream of atomized urea is introduced into the gas. The urea quantity is controlled by the urea injection control system. Mixing vanes distribute the atomized particles throughout the exhaust gas. Ammonia is formed from aqueous urea ($(NH_2)_2CO$) after the urea injection, which involves evaporation of water, thermal decomposition of urea, and finally hydrolysis of iso-cyanic acid. Evaporation of water is initiated when the aqueous urea is injected into the exhaust gas pipe. This mixture then enters the SCR housing. A chemical reaction between the ammonia from the urea, the exhaust gas NOx component, and SCR catalyst results in the reduction of the NOx into nitrogen ($N_2$), carbon dioxide ($CO_2$), and water ($H_2O$). The basic equations are:

**Urea Reaction**
$(NH_2)_2CO \rightarrow NH_3 + HNCO$
$HNCO + NOx + O_2 \rightarrow N_2 + H_2O + CO_2$

**Ammonia Reaction**
$NH_3 + NOx + O_2 \rightarrow N_2 + H_2O + CO_2$

The percent reduction of NOx is determined by the amount of urea introduced into the gas flow.

The Cat Ox/SCR system was installed in a horizontal position on a platform, elevated at a height of approximately 14 feet directly west of Engine 1 at Plant 1. This platform-mounted installation allowed for easy access to the equipment and access to the roadway underneath the platform. Figure 2-4 shows a photograph of the platform installation. The Cat Ox/SCR system was designed for the conditions and performance guarantees presented in Tables 2-1 and 2-4, respectively.

### 2.3.1. SCR/Catalytic Oxidizer System Technology and Equipment

**Oxidation Catalyst Housing**. The oxidation catalyst consisted of one Johnson Matthey Model 4040SS-4-30/36 housing for the catalyst at Engine 1. The housing has access doors on both sides of the housing, with four tracks for installing catalyst. One of the tracks houses the initial catalyst supplied, with three tracks available for later expansion if needed. There is a 30-inch flange on the inlet and a 36-inch flange on the outlet of the housing. When completely full of catalyst (4 layers), the total weight of the housing plus the catalyst is about 8,190 pounds. The housing has a number of two ¾ inch ports on the inlet and two ¾ inch ports on the outlet of the oxidation catalyst housing.

**Oxidation Catalyst.** A total of sixteen (16) whole oxidation catalyst blocks were part of this system. They were arranged 4 blocks wide x 4 blocks high x 1 block deep. [A whole block is approximately 2 feet wide x 2 feet tall x 3¼ inches deep and constitutes approximately 1 $ft^3$ of catalyst volume.] The cell density of this catalyst is 200 cells per square inch (cpsi). Figure 2-5 shows a photograph of the catalyst.

**SCR Catalyst Housing.** Johnson Matthey provided a JM Model 4040SS-4-36 housing for the catalyst. The housing was fabricated in 304 stainless steel. Two layers of catalyst were installed and there were two open tracks for addition of another layer if desired at a later date. The housing was equipped with access doors on both sides of the housing.

There are 36-inch inlet and outlet flanges (150# ANSI) provided on the housing. When completely full of catalyst (4 layers), the total weight of the housing plus the catalyst is approximately 8,190 pounds. The housing has a number of two ¾ inch ports on the inlet and two ¾ inch ports on the outlet of the SCR housing for sampling.

**SCR Catalyst.** The catalyst consists of thirty-two (32) whole SCR catalyst blocks on 200 cpsi metal substrate. They are arranged 4 blocks wide x 4 blocks high x 2 blocks deep. [A whole block is approximately 2 feet wide x 2 feet tall x 3¼ inches deep, and constitutes approximately 1 $ft^3$ of catalyst volume.]

**Urea Injection Control System.** This system was designed to control the injection rate of urea into the SCR based on engine load for one fuel blend. During the initial commissioning of the system, the engine load, the urea injection rate, and the NOx and ammonia outlet concentrations were measured and mapped. Mapping refers to the process in which the urea injection rate is correlated to the engine load in order to meet the desired NOx exhaust concentration. The system allowed for up to 25 combinations of engine load versus urea injection rate (set points).

In addition to the load map control, the injection system also uses a system of bias set points to trim the urea injection. The NOx curve bias is a percentage that can be input by the operator to increase or decrease the urea injection rate. This bias is typically set to 0%, but can be modified if engine operation is expected to change the NOx produced in the exhaust emissions. The NOx add bias increases the urea injection rate by an input gallon per hour setting based on the NOx outlet concentration from the stack exhaust CEMS analyzer. When the NOx outlet concentration reaches the level set in the control system, the urea injection rate will increase by the bias set point. The NOx subtract bias decreases the urea injection rate in the same manner. For the pilot test, no NOx subtract bias was set.

The SCR process requires precise control of the urea injection rate. An insufficient injection may result in unacceptably low NOx conversions. An injection rate that is too high can result in release of excessive ammonia emissions. These excess gaseous ammonia emissions are known as “ammonia slip”. Under the research permit for this study, the maximum allowable ammonia slip is 10 ppm. Excess ammonia can lead to clogging and equipment problems in downstream equipment. In addition, emissions of ammonia slip to the atmosphere can result in odors and a visible plume. The ammonia slip increases at higher $NH_3$/NOx ratios. The stoichiometric $NH_3$/NOx ratio is approximately 1.

### 2.3.2. Cat Ox/SCR Measurement and Monitoring Methods

**Preliminary Testing/SCR Urea Injection Mapping.** The objective of the preliminary testing was to measure the performance of the system at varying loads and fuel blends (i.e., digester gas and natural gas), and to map the urea injection system. The CO, NOx, and $O_2$ concentrations at varying engine loads and fuel distributions at the inlet of the oxidation catalyst and the outlet of the SCR catalyst were monitored for a period of six (6) hours at ten (10)-minute intervals using the TESTO® 350 XL Portable Monitor during startup as part of the preliminary testing. In addition, ammonia measurements were taken at the outlet of the SCR catalyst at ten (10)-minute intervals using Draeger® tubes. A data logger was used to monitor temperature and pressure differential on a real-time basis over the six (6)-hour testing period. Carbon monoxide was also monitored with the TESTO® 350 XL Portable Monitor. Load and fuel distribution of the engine were varied according to the schedule shown in Table 2-5. The recorded data is provided in Appendix C-1.

A secondary objective of the preliminary testing was to provide varying load and fuel scenarios for Johnson Matthey to map the urea injection system. A description of the SCR urea injection mapping during the pilot test is provided in a technical memorandum in Appendix A-4. Figure 2-6 presents a mapping diagram of the urea injection rate designed for a 95% digester gas to natural gas fuel blend during the pilot testing period after system adjustments were made on June 8, 2010.

**Source Testing Using Compliance Methods.** Source testing using SCAQMD compliance methods was performed after preliminary testing of the Cat Ox/SCR system and equipment startup and commissioning in order to measure the emissions of the system. The following summarizes the source testing using compliance methods performed on April 7-8, 2010:

- The initial testing using compliance methods was performed for one fuel blend (95% digester gas and 5% natural gas)
- Source testing was performed to sample for CO, NOx, VOCs, ammonia, and aldehydes (formaldehyde).
- SCAQMD Method 100.1 was used to measure NOx, CO, $CO_2$, and $O_2$ concentrations, modified CARB Method 430 was used to measure aldehydes (i.e., formaldehyde), Method 25.3 was used to measure total non-methane non-ethane organic compounds (NMNEOC), and modified SCAQMD Method 207.1 was used for measuring ammonia.

Table 2-6 describes details of the April 2010 initial test program using compliance methods.

## 2.4. Pilot Study Test Program Timeline

Table 2-7 presents the pilot study project timeline. The full equipment commissioning took place between March 23 and April 1, 2010. The pilot testing was conducted from April 1, 2010 through March 31, 2011. Since Engine 1 is used to provide power to the plant, it continued operation throughout the construction and commissioning of the system, with occasional stoppages as needed by the present study as well as the J-79-1 and J-79-1A projects.

**Table 2-1:**
## Engine 1 Design Parameters

| | |
|---|---|
| Manufacturer: | Cooper-Bessemer |
| Model: | LSVB-12-SGC |
| Cycle: | 4-stroke |
| Bore: | 15½ in |
| Stroke: | 22 in. |
| Configuration: | Vee-12 |
| Rated Speed: | 400 RPM |
| Rated Output: | 2,500 KW |
| BMEP: | 138 psi |
| Horsepower | 3,471 bhp |
| Load | 100% |
| Operating Hours per Year | Up to 8,760 |
| Type of Fuel | Cleaned Digester Gas / Natural Gas |
| Design Exhaust Flow Rate | 27,555 acfm |
| Design Exhaust Temperature | 800°F |

**Table 2-2:**
## DGCS Design Specifications

| | |
|---|---|
| Gas Description | Anaerobic digester gas |
| Flow | 1440 scfm |
| Pressure drop per foot of media | 0.5 in. w.c. |
| Pressure drop total with piping | 7.5 in. w.c |
| Pressure - actual | 58 psig inlet (actual) |
| Pressure - design | 150 psig |
| Maximum gas inlet Temperature | 70°F |
| Maximum Ambient Temperature | 100°F |
| Minimum Ambient Temperature | 40°F |
| Humidity | Saturated at 70°F |
| Siloxane – design | 5 ppm |
| Siloxane – current | 5 ppm |
| Total Reduced Sulfur ($H_2S$) - design | 50 ppm |
| Total VOC – design | 50 ppm |
| Siloxane removal | Below best available detection limit at time of testing (i.e. 100 ppbv per species using methanol impinger; or 500 ppbv per species in Tedlar® bag by GC/MS) |

**Table 2-3:**
## Comparison of DGCS Sampling Methods

| Comparison of DGCS Sampling Methods | |
|---|---|
| **DGCS Inlet** | **Total Siloxane (ppbv)** |
| Tedlar® – Inlet | 3,584 |
| SUMMA Canister – Inlet | 554 |
| Methanol Impinger – Inlet | 1,457 |

**Table 2-4:**
## Cat Ox/SCR Performance Guarantees

| Exhaust Component | Maximum Catalyst System Inlet (ppmv) | Maximum Catalyst System Outlet (ppmv) | Reduction Guarantee |
|---|---|---|---|
| NOx | 50 | 9 | 82.0% |
| VOC | 120 | 25 | 79.2% |
| CO | 800 | 100 | 87.5% |
| Free Ammonia Slip | N/A | 10 | N/A |

Notes: 1) Provided by Johnson Matthey price quotation, dated May 8, 2009.
2) N/A indicates not applicable. Ammonia was not measured before the catalyst.

**Table 2-5:**
## Preliminary Testing Schedule

| Test Run | Engine Load % | Natural Gas/Digester Gas Fuel Ratio (% NG / % DG) | Time Period (min) |
|---|---|---|---|
| 1 | 60 | 50 / 50 | 30 |
| 2 | 80 | 50 / 50 | 30 |
| 3 | 100 | 50 / 50 | 30 |
| 4 | 110 | 50 / 50 | 30 |
| 5 | 60 | 100 / 0 | 30 |
| 6 | 80 | 100 / 0 | 30 |
| 7 | 100 | 100 / 0 | 30 |
| 8 | 110 | 100 / 0 | 30 |
| 9 | 60 | 5 / 95 | 30 |
| 10 | 80 | 5 / 95 | 30 |
| 11 | 100 | 5 / 95 | 30 |
| 12 | 110 | 5 / 95 | 30 |

**Table 2-6:**
**Initial Pilot Study Test Program (95% Digester Gas and 5% Natural Gas)**

| Parameter | Reference Method | Load | No. of Tests | Sample Location |
|---|---|---|---|---|
| Aldehydes [1] | Modified CARB Method 430 | Max. | 2<br>2 | Catalytic Oxidizer Inlet<br>Stack Exhaust |
| Volume Flow | SCAQMD 1.1-4.1<br>EPA 19 | Max.<br>Normal<br>Min. | 1 | Stack Exhaust |
| $NO_x$, CO, $O_2$ and $CO_2$ | SCAQMD 100.1 | Max.<br>Normal<br>Min. | 1 | Stack Exhaust |
| Ammonia | Modified SCAQMD 207.1 | Max.<br>Normal<br>Min. | 2 | Stack Exhaust |
| VOCs<br>(as NMNEOC) | SCAQMD 25.3 | Max. | 1 | Catalytic Oxidizer Inlet<br>SCR Outlet<br>Stack Exhaust |
| NOx, CO, $O_2$ | CEMS | N/A | N/A | Stack Exhaust |
| NOx, $O_2$ | CEMS | N/A | N/A | Catalytic Oxidizer Inlet |

Note: 1) Aldehydes analysis included formaldehyde, acetaldehyde, and acrolein.
2) N/A indicates not applicable.

**Table 2-7:**
## Pilot Study Project Timeline

| **Action** | **Date** |
|---|---|
| Project Construction Period | 10/2009 – 3/2010 |
| **Commissioning** | |
| ■ Digester Gas Cleaning System Commissioning (AFT) | 3/9/10 |
| ■ Cat Ox/SCR System Commissioning (Johnson Matthey) | 3/22/10-3/31/10 |
| Preliminary Testing/SCR Urea Injection Mapping (Johnson Matthey) | 3/31/10 – 4/1/10 |
| **Pilot Study – Commence Testing** | **4/1/10** |
| Source Testing using Compliance Methods (SCEC) | 4/7/10 – 4/8/10 |
| Urea Injection Mapping Adjustment #1 (Johnson Matthey) | 5/13/10 |
| Urea Injection Mapping Adjustment #2 (Johnson Matthey) | 6/8/10 |
| Completed Pilot Testing | 3/31/11 |
| **Post-Pilot Study Testing** | **4/1/11 – present** |
| Urea Injection Mapping Adjustment #3 (Johnson Matthey) | 4/11/11 – 4/12/11 |

**Figure 2-1: Plant 1 Engines 1, 2, and 3 (pictured left to right)**

**Figure 2-2: Schematic of the Pilot Testing System**

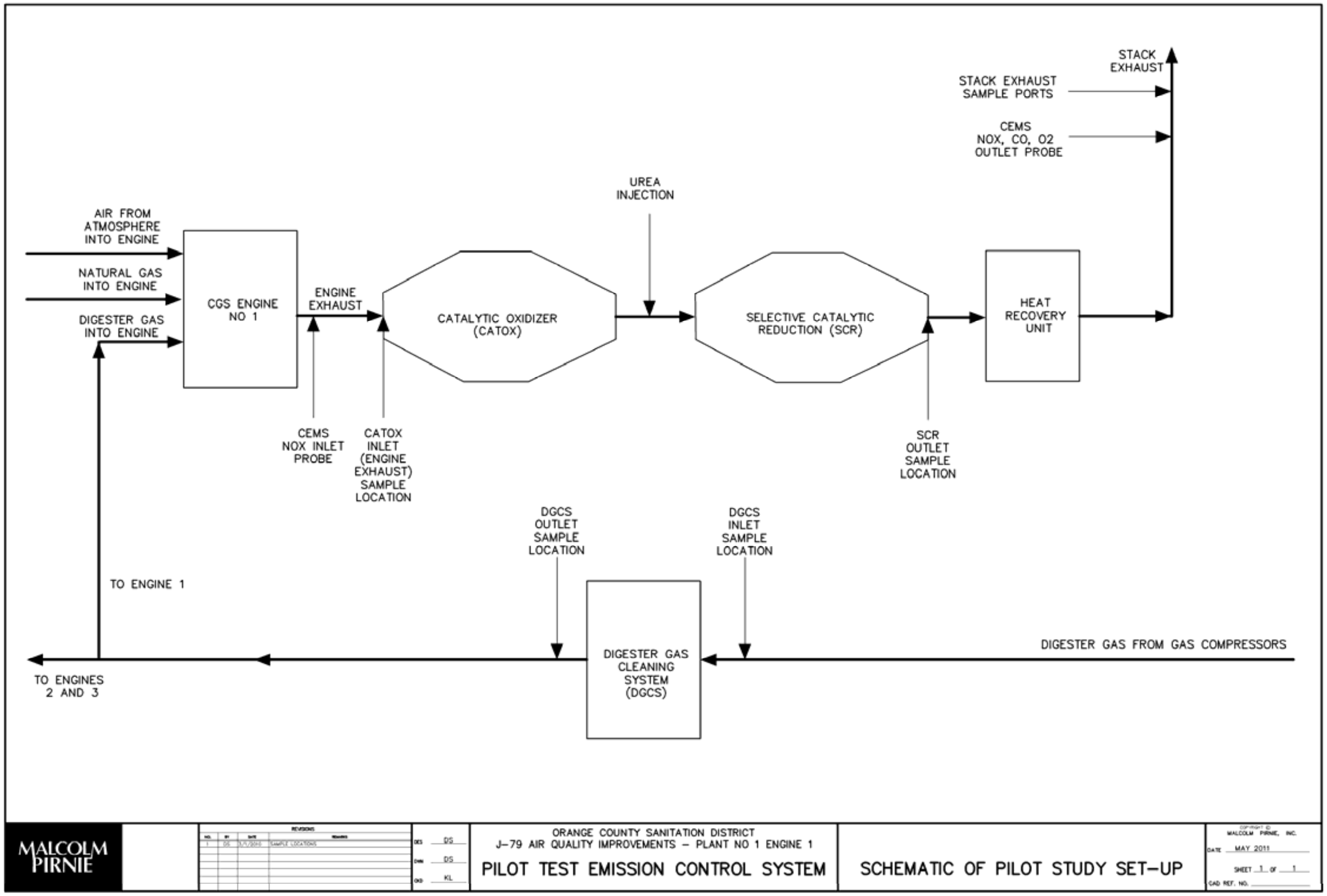


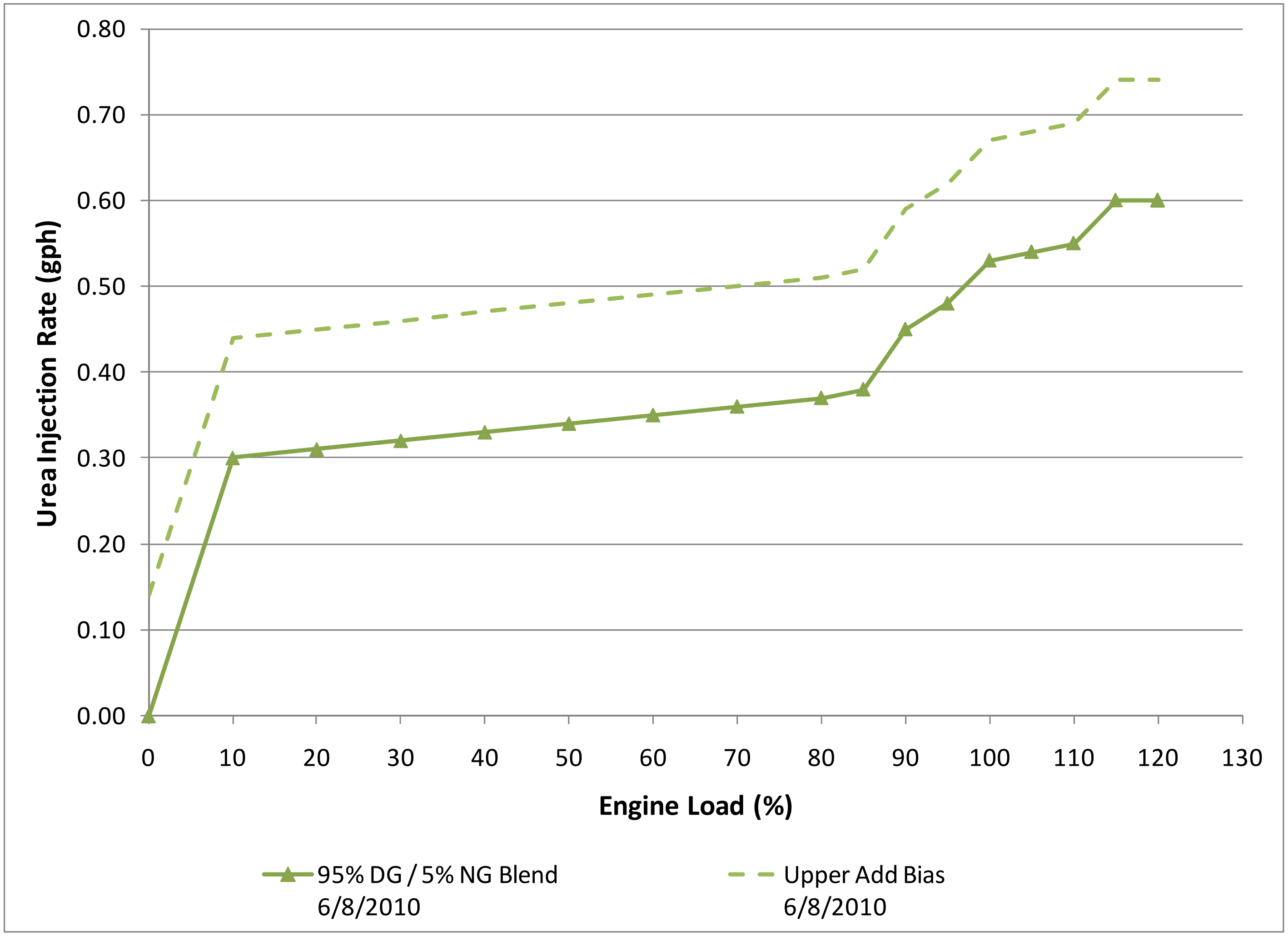
**Figure 2-3: Digester Gas Cleaning System**

**Figure 2-4: Cat Ox/SCR Platform Installation**

**Figure 2-5: Catalyst and Housing**

**Figure 2-6: SCR Urea Injection Curve for Pilot Testing**

**(June 8, 2010 through March 31, 2011)**



# 3. Results and Discussion

## 3.1. Digester Gas Cleaning System

The digester gas cleaning system installed at Plant 1 was designed to remove siloxanes and other impurities from the digester gas prior to being used to fuel the three IC engines. Throughout the pilot study, the performance of the DGCS system was evaluated by monitoring for carbon media performance and change out frequency. Samples for the family of siloxanes, $H_2S$, and speciated VOCs in the digester gas were taken at the inlet and outlet to the DGCS carbon vessel, and sent to the laboratory for testing. When the testing indicated that the DGCS media needed replacement, flow to Engine 1 was curtailed until the media was replaced. Digester gas continued to be used by Engines 2 and 3 since they were not equipped with post-combustion catalyst controls that could be fouled by the siloxanes and other contaminants in the digester gas. Once the DGCS media was replaced, the testing was resumed on Engine 1.

### 3.1.1. DGCS Sample Integrity

The composition of the digester gas at the inlet to the DGCS was tested for a number of compounds, including $H_2S$, as an indicator compound for media breakthrough, reduced sulfides, siloxanes, and a number of speciated VOCs. Since the sampling was performed using Tedlar® bags, and occasionally SUMMA canisters, the potential exists for ambient air to be captured along with the digester gas, thus diluting the sample. In order to assure that the samples were not diluted, the fixed gas composition of the gas was also measured. Fixed gases are gases for which no liquid or solid can form at the temperature of the gas, such as air at typical ambient temperatures. In the present study, $N_2$, $O_2$, $CO_2$, and $CH_4$ were the fixed gases sampled. The digester gas typically consisted of 36% carbon dioxide, 61% methane, 2% nitrogen, and less than 1% oxygen. In the event that ambient air is pulled into the digester gas sample bag, the percentage of nitrogen will be significantly greater than 2%, and the concentrations of the digester gas contaminants would be diluted.

A summary of the fixed gas composition sampling data from March 2010 through February 2011 is shown in Table 3-1. The full fixed gas composition data set is found in Appendix B-1. Over the course of this fixed gas composition sampling, three samples were eliminated due to errors in sample collection that led to a nitrogen percentage greater than 5%; one sample set (Tedlar® and Summa canister) was also eliminated due to extremely high nitrogen concentrations indicating that ambient air had leaked into the sample. However, a comparison of the inlet and outlet fixed gas composition demonstrated that the integrity of the overall digester gas samples taken was maintained with inlet and outlet concentrations of CO, $CH_4$, $N_2$, and $O_2$ staying within the range expected, indicating that the carbon media did not adsorb methane or the other fixed gases.

### 3.1.2. Digester Gas Quality

Table 3-2 presents the results of the reduced sulfides component of the digester gas. The data indicate that $H_2S$ is the biggest constituent of the reduced sulfides sampled. The average $H_2S$ concentration was approximately 26 ppmv. The high $H_2S$ input concentration makes it a good indicator compound for detecting catalyst media breakthrough at the outlet of the system. Table 3-3 presents the results of the speciated siloxane sampling. Typical of digester gases in general, D5 and D4 are the largest siloxane components of the Plant 1 digester gas. Table 3-4 presents the results of the VOC sampling. The reduced sulfide, speciated siloxane, and VOC data sets are found in Appendices B-2, B-3, and B-4, respectively.

### 3.1.3. DGCS Performance

The DGCS was monitored for carbon media performance and change out frequency throughout the study. Digester gas samples were taken at the inlet and outlet of the DGCS carbon vessel for total siloxane concentration and $H_2S$, and at the inlet for speciated siloxanes, reduced sulfides, and VOCs. Samples below the method detection level (MDL) were not used in the summary analysis.

Siloxane samples were collected using Tedlar® bags and analyzed using GC/MS at both inlet and outlet of the system. Due to the length of time required to analyze the siloxane samples (approximately several days to two weeks), $H_2S$ sampling at the DGCS outlet using Draeger tubes was used as a real-time indicator of the DGCS carbon media performance. When $H_2S$ was detected in the DGCS outlet above approximately 1 ppmv, Engine 1 was shut-down to prevent fouling of the catalyst material until the carbon media was replaced in the DGCS. The use of 1 ppmv $H_2S$ as an indicator for potential media saturation is a conservative threshold selected to ensure that media breakthrough would not occur during the study. Table 3-5 presents the results of the siloxane and $H_2S$ sampling. The table indicates that the siloxane concentrations at the inlet varied over the course of the study. As shown in Table 3-3, the average inlet concentration of total siloxanes at was approximately 5.0 ppmv. The DGCS generally removed siloxanes to below the MDL.

The carbon media was replaced three times during the pilot study: in June 2010, in September 2010, and in February 2011 after treatment of approximately 147, 174, and 157 million cubic feet of digester gas, respectively. Appendix B-5 provides a summary of reduced sulfide and speciated siloxane sampling events with DGCS carbon media use and change out frequencies. This media change-out information will be used in the cost evaluation for the overall system presented in Section 4. The effectiveness of DGCS media life may be longer than experienced during the current pilot testing because the media change-outs were conservatively scheduled to protect the catalyst. For longer term operations, a design change to optimize media life could include the installation of two vessels in series. The second vessel would act as a polisher to provide catalyst protection from siloxane breakthrough while allowing the media in the primary vessel to be completely exhausted.

## 3.2. Cat Ox/SCR System

The purpose of the demonstration project testing program was to evaluate the effectiveness of the Cat Ox/SCR system for removal of CO, VOC, and NOx to comply with amended Rule 1110.2, to monitor for ammonia slip, and to evaluate the performance of the engine with the emissions control equipment installed. The pilot testing of the Cat Ox/SCR system began on April 1, 2010, immediately after completion of the SCR urea injection mapping by Johnson Matthey. The pilot study continued until March 31, 2011.

The concentrations of CO, NOx, and $O_2$ in the engine exhaust gas before and after the Cat Ox/SCR system were determined by an independent source testing firm using SCAQMD Method 100.1, a chemiluminescent compliance testing method, during source testing on April 7 and 8, 2010. Routine monitoring of CO, NOx, and $O_2$ concentrations using OCSD's TESTO 350 XL portable handheld analyzer was also performed. The use of the portable analyzer measuring CO and NOx allowed for numerous data sets to be collected at regular intervals throughout the pilot study. The detailed portable analyzer test report can be found in Appendix C-1. In addition, a CEMS monitored and recorded the 15-minute block average NOx concentrations at the catalytic oxidizer inlet (engine exhaust) and the NOx, CO and $O_2$ concentrations at the stack exhaust. VOC concentrations were measured periodically at the engine exhaust and stack exhaust using SCAQMD Method 25.3.

The results of the source testing at Plant 1 using SCAQMD compliance methods on April 7-8, 2010 and SCAQMD Rule 1110.2 compliance testing in January 2011 are shown in Tables 3-6 and 3-7, respectively. Results for the January 2011 source testing at Plant 1 in Table 3-7 are also shown for Engines 2 and 3 for comparison. As shown in the January 2011 annual compliance test results (Table 3-7), the average NOx and CO concentrations in Plant 1 Engine 1 over three loads are 6.2 and 7.9 ppmv, respectively. This is lower than the average Engines 2 and 3 NOx and CO concentrations over three loads of 30.2 and 390.5, respectively. Results of the routine pilot test sampling events are provided in Section 3.3.

## 3.3. Compliance with Future Rule 1110.2 Emission Limits

The results of the pilot study were evaluated for compliance with the future Rule 1110.2 emission limits. The CO and VOC results represent data collected after the initial startup of the equipment from April 1, 2010 through March 31, 2011. The NOx results represent data collected after the urea injection system was optimized on June 8, 2010 through March 31, 2011.

### 3.3.1. Carbon Monoxide Concentration

CO concentration data were collected during source testing at the engine exhaust and stack exhaust routinely throughout the pilot testing period using the hand-held portable analyzer at the engine exhaust and SCR outlet and also continuously at the stack exhaust by the CEMS. The data collected during these events is summarized in Table 3-8. All CO data collected by the portable analyzer and the CEMS are presented in Appendices C-1 and C-3, respectively.

The CO concentration data at the engine exhaust (CO inlet) and the stack exhaust (CO outlet) are presented graphically in Figure 3-1. The CO inlet concentration was measured with the portable analyzer. The CO outlet concentration, measured by the CEMS, is shown as the maximum daily 15-minute average CO outlet concentration. The percent reduction in CO concentration measured across the Cat Ox/SCR system by the portable analyzer consistently exceeded 96% reduction. This performance was consistent when firing either digester or natural gas. This CO concentration removal rate exceeds the expected performance based upon the catalytic oxidizer vendor guarantee of 87.5% CO removal, provided in Table 2-4.

### 3.3.2. Volatile Organic Compounds Concentration

The VOC concentration data in terms of NMNEOC was collected during source testing at the engine exhaust, the stack exhaust, and routinely throughout the pilot testing period using SCAQMD Method 25.3. All data collected is presented in Appendix C-2. As shown in Table 3-9, the average VOC concentration at the stack exhaust was 3.58 ppmv, below the emission limit of 30 ppmv in the future Rule 1110.2.

Data measured during the pilot testing period were compared to VOC concentrations measured for the OCSD Rule 1110.2 Annual Permit Compliance Test Report for Year 2011. Table 3-7 summarizes the annual permit compliance VOC test results for OCSD Plant No. 1.

The average uncontrolled VOC concentration for Engines 2 and 3 during the compliance testing was 97 ppmv, while the controlled VOC concentration from Engine 1 stack exhaust was 3.24 ppmv. This is in the same range of the VOC concentrations measured during the pilot testing period (i.e., 3.58 ppmv), confirming the effectiveness of the catalytic oxidizer (at approximately 96%) in removing VOCs from the engine exhaust.

It should be noted that the stack exhaust VOC concentrations for Engines 2 and 3 of 97.2 and 96.9 ppmv, respectively, are much higher than the VOC concentrations measured at the Engine 1 engine exhaust during the pilot testing period, which averaged 21.84 ppmv (refer to Appendix C-2). One possible explanation to this is the arrangement of the Engine 1 sampling port before the catalytic oxidizer. Typically, when sampling using SCAQMD Method 25.3, two samples are gathered from two separate probes and the results of the analyses are averaged. In the case of this pilot study, the valve at the engine exhaust sampling port was not large enough to locate two adjacent probes, and it was not possible to expand the sampling port. Therefore, the sample and duplicate sample were not taken at the same time, but one after the other. The VOC data collected at the engine exhaust represents the higher of the two sample data results, in line with SCAQMD's general mandate that the higher value be reported when the results differ by more than 20%. Despite the lower accuracy in the engine exhaust sample due to the sizing of the sampling port, the sample taken at the stack exhaust location met the SCAQMD accuracy criteria.

### 3.3.3. Nitrogen Oxides Concentration

NOx concentration data were collected during source testing at the engine exhaust and stack exhaust, routinely throughout the pilot testing period using the portable hand-held analyzer at the engine exhaust, after the catalytic oxidizer and stack exhaust; and continuously at the engine exhaust and stack exhaust by the CEMS.

Based on the results of previous source testing, it is observed that the concentration of NOx produced in the engine exhaust for a given load is higher when firing natural gas than when firing digester gas at any given load. Therefore, the efficiency of the SCR system is reduced as the percentage of natural gas increases. The original urea injection set points, set on April 1, 2010 during commissioning, were set for a blend of digester gas and natural gas. The set points, which are a function of engine load, were adjusted on June 8, 2010 to decrease urea flow because a higher ratio of digester gas to natural gas was fired in Engine 1 than was originally anticipated. Therefore, the urea injection rates were reduced to control a lesser concentration of NOx in the exhaust gas. The data presented in this section represents the pilot testing period from June 8, 2010 through March 31, 2011. The data collected during this period are summarized in Table 3-10. The entire dataset collected is presented in Appendix C-3.

The NOx concentration data at the engine exhaust and the stack exhaust measured by the CEMS are presented graphically in Figure 3-2. The NOx inlet and outlet concentration is shown as the daily maximum 15-minute average NOx concentration. The percentage reduction in NOx concentration measured across the Cat Ox/SCR system by the portable analyzer ranged from 76 to 98%. This NOx concentration removal rate is close to the expected performance based upon the Cat Ox/SCR vendor guarantee of 82% NOx removal. A review of the NOx concentration data over the period of the pilot study indicates that the performance of the SCR is affected both by the ratio of digester to natural gas used as fuel in the engine, and by the system's responsiveness to engine operating parameters, such as start-up and differing load conditions. The inability of the

SCR system to meet the vendor guarantee may be due to periods of increased natural gas flow in the fuel gas. This was to be expected because the urea injection system was mapped for a primarily digester gas (greater than 95 percent) fuel blend. The control system can only be set with one set of engine load to urea injection set points and is not designed to change urea injection rates depending on the fuel blend. Johnson Matthey has not designed a control system that can accommodate varying loads and fuel blends. Therefore, during periods when the fuel is supplemented by natural gas, the NOx removal efficiency is expected to be reduced. If the set points were adjusted for a natural gas fuel usage, which is atypical, the system may over-inject urea potentially causing an ammonia slip as discussed below.

#### 3.3.3.1. NOx Concentrations Above Rule 1110.2 Limit

During the pilot testing period, the NOx outlet concentration occasionally spiked above the future Rule 1110.2 limit of 11 ppmv. NOx concentrations are measured continuously by the CEMS system and averaged in 15-minute blocks for compliance purposes. For the purposes of this Report, each 15-minute block is defined as a "period". A "high NOx outlet event" is defined as one period or multiple periods in a short time span where the NOx outlet concentration exceeds 11 ppmv. The NOx outlet concentration exceeded 11 ppmv for a total of 97 high NOx outlet events (940 periods out of 21,285 periods of engine operating time) during the pilot test.

Many of the high NOx outlet events were removed from the data set when evaluating performance of the SCR system. A majority of the spikes in NOx outlet concentration correlated with high NOx outlet events when: 1) the engine had just come online, 2) there was an increase in the percentage of natural gas in the engine fuel blend, 3) engine loads exceeded the loads mapped during the initial urea injection rate programming, and 4) operational adjustments of the Cat Ox/SCR system took place. Once excursions over 11 ppmv were screened for exempt or non-valid conditions such as engine start-up and non-control system error, 181 15-minute periods out of 21,285 periods of operating time (less than 0.9% of the total measurement periods during the pilot study) remained above 11 ppmv. The lowest NOx stack exhaust concentration met consistently under all valid conditions was 16 ppmv. Table 3-11 presents a break-down of the number of high NOx outlet events and periods when the NOx outlet concentration at the stack exhaust exceeded 11 ppmv.

**Exempt or Non-Valid Periods.** A total of 7 high NOx outlet events (703 periods or 3.3% of the total engine operating period) were during times when operational issues and system adjustments caused the NOx to exceed 11 ppmv. These events included urea injection system adjustments by the system vendor, operation of the SCR system without urea in the storage tank, modifications to the engine automation system, improper operation of the SCR system, and clogging in the urea injection lance. These periods were removed from the stack exhaust NOx data set because they do not represent proper operating conditions of the SCR system.

During the pilot testing period, 29 high NOx outlet events (56 periods or 0.3% of the total engine operating time) were classified as occurring during engine start-up. Rule 1110.2(h)(10) allows for an exemption during engine start-up to allow for sufficient operating temperatures to be reached for proper operation of the emission control equipment. The start-up period is limited to 30 minutes unless a longer period is approved for a specific engine by the Executive Officer and is made a condition of the engine permit. Periods where NOx outlet concentrations exceeded 11 ppmv within 30 minutes of engine start-up were removed from the data set for evaluation of the SCR system performance.

**Validated Periods.** A number of the remaining high NOx outlet events could be attributed to periods during which the engine was operating with natural gas fuel or at a load that exceeded the range that was originally mapped into the urea injection system. The urea injection system was programmed assuming a fuel blend of 95% digester gas to 5% natural gas. An event was attributed to a rise in natural gas usage if the fuel blend decreased to below 95% digester gas during the same period or during the period immediately preceding the event. A total of 17 high NOx outlet events (43 periods or 0.2% of total engine operating time) occurred when the fuel blend decreased to below 95% digester gas. It was observed that the production of NOx at the engine exhaust increased as the percentage of natural gas in the engine fuel increased. Therefore, as the digester gas to natural gas fuel ratio decreased to below 95% digester gas (i.e., using more natural gas in the fuel blend), the urea injection system would not inject a sufficient quantity of urea to compensate for the additional NOx being produced and NOx outlet concentration would increase.

A total of 22 high NOx outlet events (63 periods or 0.3% of the total engine operating time) occurred when the engine load exceeded 100%. During the pilot testing period, the urea injection rate setpoints were set for an engine load range of 0% to 100%. An event was considered to be due to an increase in engine load if the engine load increased to above 100% during the same period or during the period immediately preceding the event. When the engine load exceeded 100% of design load for an extended period of time, the urea injection rate was not able to adjust properly because the engine operation surpassed the programming of the system.

There are 22 high NOx outlet events (75 periods or 0.4% of the total engine operating time) that could not be attributed to operational issues/system adjustments, engine start-up, increased natural gas fuel usage, or high engine load. The NOx outlet concentrations during the majority of these periods typically ranged between 11 and 12 ppmv, with a maximum of 16 ppmv.

The maximum NOx concentration at the outlet was 16 ppmv after removing the non-control system related exceedances, including operational issues/system adjustments and engine start-up. The validated average, minimum, and maximum NOx outlet concentrations recorded by the CEMS are presented in Table 3-12. The validated data set includes the NOx outlet concentration data during increased natural gas fuel usage, high engine load, and other high NOx outlet events not attributed to operational issues/system adjustments, engine start-up, increased natural gas fuel usage, or high engine load. Following the pilot test, the urea injection setpoints and biases may be increased to account for increased NOx production due to increased natural gas in the fuel blend and higher engine loads. Increasing the urea injection setpoints may also reduce the number of other high NOx outlet events that fall just above the 11 ppmv NOx limit.

In April 2011, after the official pilot testing period concluded, a Johnson Matthey technician adjusted the urea injection rate curve to 1) expand the curve to a maximum of 125% engine load and 2) to increase the urea injection rate at high engine loads. The increase in urea injection rate should accommodate for the increased NOx production when the engine incorporates more natural gas into the fuel blend. Further observation will be required to confirm if these adjustments will lead to a reduction in the number of periods where stack exhaust NOx outlet concentration exceeds 11 ppmv.

### 3.3.4. Ammonia Concentration

The SCR system reduces NOx through a chemical reaction between ammonia and NOx, facilitated by a catalyst to form nitrogen and water vapor. Once urea is injected into the engine exhaust stream, it breaks down into ammonia and other constituents. Hydrolysis of the urea on the face of the catalyst generates more ammonia. While NOx reduction is the goal of the SCR system through the consumption of the ammonia, injection of too much urea can result in excess ammonia (total ammonia) at the SCR outlet in the form of free ammonia ($NH_3$), and/or other ammonia-formed compounds. Parts of the total ammonia can then participate in secondary reactions with other compounds in the exhaust gas forming by-products, such as ammonium sulfates (combined ammonia). These secondary ammonia by-products may have the undesirable potential to increase maintenance requirements on the equipment downstream from the SCR, due to clogging and particulate buildup. The remaining gaseous ammonia (free ammonia) that is emitted at the stack exhaust is referred to as ammonia slip. SCAQMD regulated the amount of ammonia slip in the Pilot Study Research Permit not to exceed 10 ppmv of free ammonia at the stack exhaust.

Three methods were used for determining ammonia concentration:

- On-site field measurement of free ammonia using Draeger® or Sensidyne® tubes,
- Modified SCAQMD Method 207.1 to measure free ammonia, and

- Estimated total ammonia concentration (free plus combined ammonia) calculation method using inlet and outlet NOx CEMS concentrations and the urea injection rate.

Free ammonia concentration data was collected during source testing at the stack exhaust using modified SCAQMD Method 207.1, and also routinely monitored throughout the pilot testing period using Draeger® tubes or Sensidyne® tubes at the SCR outlet. Both tests provide concentration data for free ammonia. Total ammonia was also calculated from the CEMS data based on the NOx inlet and outlet concentrations and the urea injection rate. The limitations of this total ammonia calculation are discussed in detail in a technical memorandum *OCSD Cat Ox/SCR Pilot Study: Ammonia Sampling and Calculation Methods* (Malcolm Pirnie, May 2011) found in Appendix C-2. As with the NOx data, the ammonia data presented in this section represents data collected during the pilot testing in the period from June 8, 2010 through March 31, 2011, after the urea injection rate set points were adjusted on June 8, 2010. Figure 3-3 presents the maximum total ammonia estimate for each day of the pilot test between these dates using the calculation method.

Over the course of the pilot testing period, the Draeger® tubes consistently measured free ammonia concentrations at the stack exhaust below MDL. During the same time period when the ammonia field measurements were taken, the calculated total ammonia concentration using the 15-minute block averages reported by the CEMS had a value ranging from 0 to 5 ppm of ammonia.

**Estimated Total Ammonia Calculation.** The calculation method for total ammonia is dependent on the NOx inlet and NOx outlet concentrations and the urea injection rate, which is continuously adjusting based on the engine load and the NOx outlet concentration. The ammonia calculation equation is shown below, where CF can be used as a correction factor to account for factors such as secondary reactions and limitations of the urea injection system, and as a tool to adjust the calculation of total ammonia to estimate free ammonia.

$$NH_3 = [\text{Urea Fed} - (\text{NOx in} - \text{NOx out}) /2] \times CF$$

The CF was assumed to be equal to 1 in the present study. Throughout the pilot testing, differences were observed between the free ammonia measured in the field and total ammonia estimated using the calculation method. The calculation method assumes that the ammonia/NOx reaction is the only reaction consuming the urea. There is the potential for ammonia molecules to be consumed in other secondary reactions in the exhaust stream, such as those with sulfur compounds. Sulfur dioxide ($SO_2$) and sulfur trioxide ($SO_3$) can react with ammonia to produce ammonium sulfate ($NH_4HSO_4$) and ammonia bisulfate (ammonia hydrogen sulfate) ($(NH_4)_2SO_4$) which can precipitate out of the exhaust gas at low temperatures (300-450°F) as ammonium salts (combined ammonia). Ammonium salts have the potential to deposit on equipment downstream from the SCR catalyst, such as the heat recovery boiler, reducing their efficiency and increasing maintenance requirements. Field measurements during the pilot test were only performed for free ammonia which did not include ammonia compounds, such as the ammonium salts. Low ammonia concentration Draeger® tube measurements combined with the and high exhaust gas temperatures (~ 800°F) taken directly after the SCR catalyst indicate that the potential for these secondary reactions is low.

Engine load fluctuates with time. When the IC engines are set to a base load, it was observed that the actual engine load fluctuated rapidly by as much as ten percent below the set point. This was found to be typical for the OCSD IC engines. However, since urea injection rate is mapped to engine load, the rapid fluctuations in load can result in rapid changes in urea injection rates. Rapidly changing urea injection rates, instead of steady rates with smooth transitions, can cause inaccuracies in the ammonia calculation.

**SCAQMD Sampling Using Compliance Methods.** Free ammonia was measured at the stack exhaust once during the initial source testing event from April 7-8, 2010, and once after the pilot testing period on May 10, 2011. On both occasions, ammonia slip concentrations at three engine loads measured by Modified SCAQMD Method 207.1 were found to be less than 0.5 ppmv. Neither the Draeger® tube nor Sensidyne® tube free ammonia measurements at the SCR exhaust were above the MDL. However, the total ammonia estimate based on the theoretical calculation using the CEMS data was three to ten times higher than the measured value using the compliance method. Results of these sampling events are compared in Table 3-13.

Further sampling of the exhaust emissions can be performed to establish a value for the correction factor, CF, in the estimated total ammonia calculation method for the calculation of free ammonia. If found, the presence of sulfur dioxide and sulfur trioxide in the exhaust gas before the SCR, and ammonium sulfate and ammonia bisulfate, in the exhaust gas after the SCR, can indicate secondary reactions taking place due to the injection of urea. In addition, inspection of the heat recovery boiler during the next scheduled maintenance may also indicate the presence of ammonium salts in the exhaust gas. A correction factor can be applied to the estimated total ammonia calculation to account for these secondary reactions, thus allowing for the estimation of free ammonia. If ammonium salts are identified in the heat recovery boiler, adjustments to the urea injection rates or additional maintenance of the heat recovery boiler may be required.

Compliance monitoring for free ammonia is more accurate when reflective of gaseous ammonia emitted from the stack, while the estimated total ammonia calculation method may reflect both free ammonia and ammonia by-products produced in the exhaust gas. Although the pilot study data indicates that there is minimal, if any, free ammonia (ammonia slip) due to the SCR system, it is recommended that the OCSD perform additional and routine testing for ammonia slip during varying loads and fuel blends over a period of time.

## 3.4. Engine Performance

A significant amount of operational data was collected throughout the pilot test. The data logger installed within the urea injection control cabinet collected additional data beyond that collected by the CEMS. These data included the temperature at the catalytic oxidizer inlet and outlet, and the SCR inlet and outlet and the differential pressure across the catalytic oxidizer and SCR catalysts. The system urea injection and back pressure performance proposed by Johnson Matthey is provided in Table 3-14. The data collected by the data logger are summarized in Table 3-15 and were validated to remove periods when the engine was offline. Periods when the engine was offline were identified as those periods when the urea injection is offline, when the temperatures in the catalyst housings cool and the NOx inlet concentration decreases to zero.

During the pilot test, there were no notable back pressure effects on engine performance due to the installation of the Cat Ox/SCR system with a digester gas cleaning system. The engine manufacturer's allowable back pressure is 20 inches of water column (in. wc.). The engineering design estimate of the maximum engine exhaust system back pressure without the Cat Ox/SCR system was 11 in. wc. Therefore, the available system design back pressure for the Cat Ox/SCR system and additional exhaust ductwork was 9 in. wc. Based on the data provided by the data logger in during the pilot test, the average differential pressure through the catalytic oxidizer and SCR are approximately 0.3 and 1.0 in. wc., respectively. Therefore, it is concluded that the system does not negatively affect engine performance.

The exhaust gas temperature reported through the catalytic oxidizer and SCR and the urea injection rate indicate proper system performance. The average inlet and outlet temperature through both catalysts is between 750°F and 800°F, which is in the proper temperature range for ammonia to react in the SCR catalyst. The actual urea injection rate of approximately 0.6 gallons per hour (gph) is also below the urea usage estimate of 1.1 gph proposed by Johnson Matthey.

The DGCS has had a positive effect on engine performance. The use of cleaned digester gas at Plant 2 Engine 3 resulted in much less frequent maintenance requirements for the engine, including longer time intervals between spark plug changes and major maintenance events. OCSD Operations continues to use the DGCS from the 2007 pilot study at Plant 2 Engine 3 after improvements in performance of the engine and maintenance cost savings resulted from use of the DGCS. These savings are discussed further in Section 4.

## 3.5. Summary of System Results

The overall results of the pilot study are:

- The maximum NOx concentration at the stack exhaust after the pilot study controls was approximated 16 ppmv, and the average NOx concentration was approximately 7.2 ppmv, below the 11 ppmv required under amended Rule 1110.2. Further adjustment of the urea injection rate was performed after the end of the pilot study, and these new data will be evaluated further to determine if this urea injection rate modification will eliminate excursions above 11 ppmv.
- While there were some excursions above 11 ppmv, once these excursions were screened for exempt conditions like start-up, and non-control system error, less than 0.9% of the total measurement periods during the pilot study, or 181 15-minute periods out of 21,285 periods in total remained above 11 ppmv.
- Using monitoring data for gaseous free ammonia collected using the SCAQMD method and Draeger® tube method, the free ammonia concentration was below 0.5 ppmv and MDL over the pilot study, respectively.
- Based on the calculation method for total ammonia, the maximum total ammonia concentration during ammonia concentration sampling events was estimated to be 4.65 ppmv. It is believed that this is an overestimate due to limitations of the calculation, such as not accounting for potential secondary ammonia reactions. Despite this, the estimated total ammonia calculation method can be used as a tool to prompt a field measurement to determine free ammonia (ammonia slip) with the application of an appropriate correction factor, CF. Further evaluation needs to be performed to develop a correction factor that will correlate the calculation method and the measured values of free ammonia.
- The percentage reduction in CO concentration measured across the Cat Ox/SCR system by the portable analyzer ranges consistently exceeded a 96% reduction in CO concentration from the engine exhaust.
- The maximum CO concentration at the stack exhaust using the CEMS data was 42.2 ppmv, well below the amended Rule 1110.2 emission limit of 250 ppmv.
- The catalytic oxidizer was found to result in removing approximately 96 % VOCs from the engine exhaust.
- The maximum VOC concentration at the stack exhaust was found to be 5.42 ppmv using Method 25.3, and consistently well below the 30 ppmv in amended Rule 1110.2.

- The DGCS system, in general, removed siloxanes from the digester gas to below MDL levels and significantly reduced sulfur compounds and VOCs successfully reducing catalyst masking which should lead to extended catalyst life.
- The DGCS system resulted in overall improvements in engine maintenance requirements.
- No back pressure concerns for the engine due to the additional equipment were identified.

**Table 3-1:**
**Summary of Fixed Gases in Plant 1 Digester Gas**

| Fixed Gas | DGCS Inlet | | | DGCS Outlet | | |
|---|---|---|---|---|---|---|
| | Min. | Max. | Avg. | Min. | Max. | Avg. |
| | (%) | (%) | (%) | (%) | (%) | (%) |
| Carbon Dioxide ($CO_2$) | 25.5 | 40.1 | 33.9 | 23.1 | 37.2 | 32.8 |
| Methane ($CH_4$) | 53.7 | 62.6 | 58.7 | 45.0 | 62.5 | 58.0 |
| Nitrogen ($N_2$) | 0.9 | 5.1 | 2.2 | 1.1 | 1.9 | 1.5 |
| Oxygen ($O_2$) | 0.1 | 1.4 | 0.6 | 0.1 | 0.8 | 0.4 |

**Table 3-2:**
**Summary of Reduced Sulfides in Plant 1 Digester Gas**

| Compound | DGCS Inlet | | |
|---|---|---|---|
| | Min. (ppmv) | Max. (ppmv) | Avg. (ppmv) |
| Hydrogen Sulfide | 14.7 | 31.9 | 26.4 |
| Carbonyl Sulfide | 0.01 | 0.03 | 0.02 |
| Methyl Mercaptan | 0.05 | 0.08 | 0.06 |
| Ethyl Mercaptan | 0.2 | 0.3 | 0.3 |
| Dimethyl Sulfide | 0.006 | 0.02 | 0.01 |
| Carbon Disulfide | 0.004 | 0.009 | 0.006 |
| n-Propyl Thiol | 0.5 | 0.8 | 0.6 |
| iso-Propyl Thiol | 0.2 | 0.4 | 0.3 |
| Dimethyl Disulfide | ND | ND | ND |
| Isopropyl Mercaptan | 0.3 | 0.3 | 0.3 |
| n-Propyl Mercaptan | 0.3 | 0.3 | 0.3 |

Note: 1) ND indicates non-detect.

**Table 3-3:**
**Summary of Speciated Siloxanes in Plant 1 Digester Gas**

| Compound | DGCS Inlet | | |
|---|---|---|---|
| | Min. (ppbv) | Max. (ppbv) | Avg. (ppbv) |
| Hexamethyldisiloxane (L2) | <MDL | <MDL | <MDL |
| Hexamethylcyclotrisiloxane (D3) | 10 | 17 | 12 |
| Octamethyltrisiloxane (L3) | 10 | 19 | 14 |
| Octamethylcyclotetrasiloxane (D4) | 369 | 1,600 | 704 |
| Decamethyltetrasiloxane (L4) | 73 | 170 | 121 |
| Decamethylcyclopentasiloxane (D5) | 1,300 | 14,000 | 5,371 |
| Total Siloxanes | 919 | 15,700 | 5,452 |

Note: MDL is mean detection level.

**Table 3-4:**
## Summary of Speciated VOCs in Plant 1 Digester Gas

| Analyte | DGCS Inlet | | |
|---|---|---|---|
| | Min. (ppbv) | Max. (ppbv) | Avg. (ppbv) |
| Acetone | 7.0 | 88.0 | 26.0 |
| Benzene | 7.3 | 15.7 | 10.7 |
| Chlorobenzene | 4.5 | 6.4 | 5.4 |
| Cyclohexane | 4.9 | 22.0 | 13.6 |
| 1,4-Dichlorobenzene | 5.0 | 28.0 | 16.4 |
| cis-1,2-Dichloroethene | 17.2 | 103.0 | 41.4 |
| trans-1,2-Dichloroethene | 4.6 | 4.6 | 4.6 |
| Ethyl Acetate | 22.2 | 22.2 | 22.2 |
| Ethylbenzene | 37.0 | 141.0 | 74.2 |
| 4-Ethyltoluene | 12.7 | 68.6 | 33.7 |
| Freon 11 | 5.2 | 6.3 | 5.8 |
| n-Heptane | 57.8 | 122.0 | 84.2 |
| Hexane | 27.0 | 210.0 | 76.5 |
| Methylene Chloride | 5.2 | 14.0 | 8.9 |
| Methyl Isobutyl Ketone (MIBK) | 4.4 | 4.5 | 4.4 |
| Propene | 2,410 | 3,730 | 3,226 |
| Styrene | 4.2 | 24.7 | 10.7 |
| Tetrachloroethene (PCE) | 11.0 | 11.0 | 11.0 |
| Tetrachloroethylene | 6.0 | 26.3 | 13.5 |
| Toluene | 1,090 | 7,300 | 2,296 |
| 1,2,4-Trichlorobenzene | 9.2 | 9.2 | 9.2 |
| Trichloroethene (TCE) | 9.6 | 28.0 | 15.8 |
| Trichloroethylene | 6.2 | 22.9 | 11.7 |
| 1,2,4-Trimethylbenzene | 67.1 | 240.0 | 123.1 |
| 1,3,5-Trimethylbenzene | 30.0 | 88.0 | 45.8 |
| 2,2,4-Trimethylpentane | 27.0 | 66.0 | 52.0 |
| m & p-Xylene | 47.0 | 180.0 | 96.1 |
| o-Xylene | 20.0 | 64.0 | 36.3 |
| Total VOCs | **1,594** | **11,133** | **4,927** |

**Table 3-5:**
## Summary of Siloxane and $H_2S$ Sampling

| Date of Sampling | Approximate Volume of Gas Treated (million cubic feet) | Total Siloxane | | $H_2S$ | | | |
|---|---|---|---|---|---|---|---|
| | | | | SCAQMD 307-91 | | Draeger Tube | |
| | | Inlet (ppmv) | Outlet (ppmv) | Inlet (ppmv) | Outlet (ppmv) | Inlet (ppmv) | Outlet (ppmv) |
| 3/16/2010 | 0.00 | 3.58 | <MDL | N/A | N/A | N/A | N/A |
| 4/7/2010 | 27.26 | 8.51 | <MDL | N/A | N/A | N/A | N/A |
| 4/21/2010 | 53.41 | N/A | N/A | 25.70 | ND | 26 | ND |
| 4/29/2010 | 68.93 | 15.70 | ND | N/A | N/A | N/A | N/A |
| 5/11/2010 | 91.86 | N/A | N/A | 31.70 | 0.263 | 31 | ND |
| 5/27/2010 | 122.58 | 2.67 | 0.015 | N/A | N/A | N/A | N/A |
| 6/8/2010 | 144.70 | N/A | N/A | 27.97 | 2.162 | 30 | 2 |
| 6/11/2010 | 146.46 | 8.49 | 0.248 | N/A | N/A | N/A | N/A |
| 6/12/2010 | Carbon media changed. | | | | | | |
| 6/22/2010 | 18.44 | N/A | N/A | 21.62 | ND | 27 | N/A |
| 6/29/2010 | 32.70 | 8.69 | N/A | N/A | N/A | N/A | N/A |
| 7/7/2010 | 46.34 | N/A | N/A | 28.57 | ND | 25 | N/A |
| 7/21/2010 | 68.89 | N/A | N/A | 24.87 | ND | 25 | N/A |
| 8/3/2010 | 90.04 | N/A | N/A | 27.45 | ND | 25 | N/A |
| 8/12/2010 | 106.00 | N/A | N/A | 28.19 | ND | 26 | N/A |
| 8/12/2010 | 106.00 | 3.73 | ND | N/A | N/A | N/A | N/A |
| 9/1/2010 | 137.15 | 4.57 | <MDL | N/A | N/A | N/A | N/A |
| 9/1/2010 | 137.15 | N/A | N/A | 14.69 | ND | 14 | N/A |
| 9/14/2010 | 162.45 | N/A | N/A | 23.01 | 0.545 | 23 | N/A |
| 9/15/2010 | 164.63 | 4.35 | <MDL | N/A | N/A | N/A | N/A |
| 9/17/2010 | 168.63 | N/A | N/A | N/A | N/A | N/A | 2.5 |
| 9/20/2010 | 173.62 | 5.73 | <MDL | N/A | N/A | N/A | N/A |
| 9/21/2010 | Carbon media changed. | | | | | | |
| 11/4/2010 | 43.40 | 5.23 | N/A | N/A | N/A | N/A | N/A |
| 1/12/2011 | 114.53 | 6.55 | N/A | N/A | N/A | N/A | N/A |
| 1/25/2011 | 137.78 | N/A | N/A | 28.54 | ND | 27 | N/A |
| 2/9/2011 | 156.47 | N/A | N/A | 31.87 | 1.755 | 30 | N/A |
| 2/9/2011 | 156.47 | 4.58 | <MDL | N/A | N/A | N/A | N/A |
| 2/14/2011 | Carbon media changed. | | | | | | |
| 2/23/2011 | 17.72 | N/A | N/A | 24.46 | ND | 25 | N/A |
| 2/24/2011 | 20.09 | 6.64 | N/A | N/A | N/A | N/A | N/A |

Notes: 1) All samples are taken using Tedlar® bags, except where otherwise noted as using Draeger® tubes for $H_2S$.
2) Inlet and outlet sample results from 5/19/10 are not accurate due to an error in collection, indicated by high nitrogen composition (>5%), and are not included in the minimum, maximum and average.

3) Outlet sample results from 6/29/10 are not accurate due to an error in collection, indicated by high nitrogen composition (>5%), and are not included in the minimum, maximum and average.
4) Inlet and outlet sample results from AccuLabs on 8/12/10 are not accurate due to an error in collection, indicated by high nitrogen composition (>5%), and are not included in the minimum, maximum and average.
5) Sample results from 8/19/10 are not consistent with sample results from other laboratories and are concluded to be erroneous and not included in the minimum, maximum and average.
6) N/A indicates that the compound was not analyzed.
7) ND indicates non-detect.
8) <MDL indicates less than the Method Detection Limit.

**Table 3-6:**
## Plant 1 Engine 1 April 7-8, 2010 Testing using SCAQMD Compliance Methods

| Parameter | Units | Low Load | Normal Load | High Load | Average Load |
|---|---|---|---|---|---|
| Load | KW | 1,598 | 2,303.5 | 2,515.8 | 2,139.1 |
| | % | 65 | 90 | 105 | 86.7 |
| Volume Flow | dscfm | 5,662 | 8,423 | 9,244 | 7,776.3 |
| Fuel Flow | NG scfm | 14.2 | 19.7 | 20.8 | 18.2 |
| | DG scfm | 470.7 | 635.3 | 688.8 | 598.3 |
| **Stack Exhaust** | | | | | |
| NOx | ppm | 6.5 | 4.7 | 8.5 | 6.6 |
| CO | ppm | 7.3 | 4.9 | 4.9 | 5.7 |
| TGNMNEO | ppm | N/A | N/A | 2.6 | 2.6 |
| Formaldehyde | ppm | N/A | N/A | 0.434 | N/A |
| Acetaldehyde | ppm | N/A | N/A | 0.023 | N/A |
| Acrolein | ppm | N/A | N/A | < MDL | N/A |
| Ammonia | ppm | 0.12 | 0.18 | 0.43 | 0.2 |
| $O_2$ | % | 10.59 | 11.97 | 12.03 | 11.5 |
| $CO_2$ | % | 8.56 | 7.55 | 7.69 | 7.9 |
| **Engine Exhaust** | | | | | |
| TGNMNEO | ppm | N/A | N/A | 25.86 | N/A |
| Formaldehyde | ppm | N/A | N/A | 21.44 | N/A |
| Acetaldehyde | ppm | N/A | N/A | 0.419 | N/A |
| Acrolein | ppm | 0.18 | 0.18 | < MDL | N/A |

Notes: 1) N/A indicates not applicable.

2) <MDL indicates less than the Method Detection Limit.

**Table 3-7:**
**SCAQMD Rule 1110.2 Year 2011 Permit Compliance Test Report**

| Parameter | Units | Low Load | Normal Load | High Load | Average Load |
|---|---|---|---|---|---|
| **Engine 1** | | | | | |
| Load | KW | 1,655 | 1,929 | 2,438 | 2,183.5 |
| | % | 66 | 77 | 98 | 87.3 |
| Volume Flow | dscfm | 6,194 | 7,406 | 9,124 | 8,265.0 |
| NOx | ppm | 4.6 | 5.4 | 6.9 | 6.2 |
| CO | ppm | 6.2 | 7.6 | 8.2 | 7.9 |
| TGNMNEO | ppm | N/A | 3.2 | N/A | N/A |
| PM | gr/dscf | N/A | 0.0 | N/A | N/A |
| $O_2$ | % | 10.90 | 11.84 | 12.16 | 12.00 |
| $CO_2$ | % | 8.59 | 7.83 | 7.52 | 7.68 |
| **Engine 2** | | | | | |
| Load | KW | 1,618 | 1,852 | 2,455 | 2,153.7 |
| | % | 65 | 74 | 98 | 86.2 |
| Volume Flow | dscfm | 6,513 | 7,598 | 9,867 | 8,732.5 |
| NOx | ppm | 27.8 | 27.6 | 31.6 | 29.6 |
| CO | ppm | 348.7 | 390.4 | 432.3 | 411.4 |
| TGNMNEO | ppm | N/A | 97.2 | N/A | N/A |
| PM | gr/dscf | N/A | 0.0010 | N/A | N/A |
| $O_2$ | % | 11.79 | 12.04 | 12.53 | 12.29 |
| $CO_2$ | % | 7.80 | 7.60 | 7.16 | 7.38 |
| **Engine 3** | | | | | |
| Load | KW | 1,748 | 1,981 | 2,488 | 2,234.6 |
| | % | 70 | 79 | 100 | 89.4 |
| Volume Flow | dscfm | 6,703 | 7,746 | 9,652 | 8,699.0 |
| NOx | ppm | 29.1 | 30.1 | 31.2 | 30.7 |
| CO | ppm | 317.3 | 343.8 | 394.7 | 369.3 |
| TGNMNEO | ppm | N/A | 96.9 | N/A | N/A |
| PM | gr/dscf | N/A | 0.0049 | N/A | N/A |
| $O_2$ | % | 11.68 | 12.01 | 12.49 | 12.25 |
| $CO_2$ | % | 7.87 | 7.57 | 7.18 | |

Notes: 1) N/A indicates not applicable

## Table 3-8:
## Summary of CO Concentrations from Inlet and Outlet of Cat Ox/SCR System

| Sampling Method | Catalytic Oxidizer Inlet Concentration (ppmvd)[1] | | | SCR Outlet/Stack Exhaust Concentration (ppmvd)[1] | | |
|---|---|---|---|---|---|---|
| | Min. | Max. | Avg. | Min. | Max. | Avg. |
| Portable Analyzer[2] | 367.5 | 598.7 | 451.6 | <MDL | 17.2 | 5.8 |
| CEMS [3] | N/A[4] | N/A[4] | N/A[4] | 4.0 | 42.2 | 7.5 |

Notes:
1) Concentrations are presented in parts per million by volume dry (ppmvd) at 15% $O_2$
2) CO concentrations by portable analyzer are measured routinely starting on April 7, 2010, after initial mapping of the SCR system.
3) NOx and CO CEMS data is based on an average of the 15-minute average NOx and CO concentrations for each calendar day. .
4) N/A: CEMS measures CO at the stack exhaust only; therefore, there is no CEMS data at the Cat Ox inlet.

**Table 3-9:**
**VOC Concentrations at Stack Exhaust**

| Date | Stack Exhaust (ppmv) |
|---|---|
| 4/7/2010 | 2.60 |
| 5/11/2010 | 0.73 |
| 8/12/2010 | 5.42 |
| 11/4/2010 | 4.21 |
| 2/24/2011 | 4.95 |
| Average | 3.58 |

Notes: All concentrations are adjusted to 15% $O_2$.

**Table 3-10:**
**Summary of NOx Concentrations[1] at Inlet and Outlet of Cat Ox/SCR System**

| Sampling Method | Catalytic Oxidizer Inlet Concentration (ppmvd) | | | Catalytic Oxidizer Outlet Concentration (ppmvd) | | | SCR Outlet/Stack Exhaust Concentration (ppmvd) | | | NOx Reduction (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Min.** | **Max.** | **Avg.** | **Min.** | **Max.** | **Avg.** | **Min.** | **Max.** | **Avg.** | **Avg.** |
| SCAQMD Method 100.1[2] | --- | --- | --- | --- | --- | --- | N/A | N/A | 6.6 | N/A |
| Portable Analyzer [3] | 37.9 | 43.5 | 40.9 | 36.4 | 44.0 | 40.1 | 6.9 | 10.2 | 8.4 | 79.5 |
| CEMS [4] | 19.3 | 64.7 | 30.7 | --- | --- | --- | 0.8 | 15.9 | 7.2 | 77 |

Notes:
1) Concentrations are presented in parts per million by volume dry (ppmvd) at 15% $O_2$.
2) Method 100.1 measurements by SCEC were performed at the stack exhaust only.
3) NOx concentrations by portable analyzer are measured routinely starting on April 7, 2010, after initial mapping of the SCR system.
4) NOx and CO CEMS data is based on an average of the 15-minute average NOx and CO concentrations for each calendar day. CEMS data was not collected at the Cat Ox outlet.
5) N/A indicates not applicable.

**Table 3-11:**
**Count of Periods and Events with NOx Concentration Above 11 ppmvd**

| **Number of 15-minute periods when NOx stack exhaust concentration exceeded 11 ppmvd** | | **Total High NOx Outlet Events[4]** | **% of Total Operating Time[5]** |
|---|---|---|---|
| Operational Issues and System Adjustments[1, 2] | 703 | 7 | 3.3 |
| Engine start-up (30 minutes)[3] | 56 | 29 | 0.3 |
| **Total Non-Valid** | **759** | **36** | **3.6** |
| Increase in NG Fuel Composition | 43 | 17 | 0.2 |
| High Load (>100%) | 63 | 22 | 0.3 |
| Other | 75 | 22 | 0.4 |
| **Total Valid** | **181** | **61** | **0.9** |
| **Total** | **940** | **97** | **4.5** |

Notes:
1) Operational issues occurred 7/1/10-7/4/10, 12/29/10-1/4/11, 3/14/11, 3/17/11, and 3/22/11.
2) NOx at the stack exhaust exceeded 11 due to system adjustments to the urea injection system.
3) The first 30 minutes after start-up of the engine are exempt from amended Rule 1110.2. Data was excluded where NOx at the stack exhaust exceeded 11 ppmvd during engine start-up.
4) An "event" is defined as one or more consecutive 15-minute periods or periods in close succession where the NOx outlet concentration exceeded 11 ppmvd.
5) The total engine operating time is 21,285 15-minute periods (approximately 5,321 hours).

**Table 3-12:**
## Summary of All vs. Validated NOx Inlet and Outlet Concentrations

| Parameter | NOx Engine Exhaust (ppmvd) | All NOx Stack Exhaust (ppmvd) | Validated NOx Stack Exhaust (ppmvd) |
|---|---|---|---|
| Average | 30.68 | 7.53 | 7.16 |
| Minimum | 10.72 | 0.80 | 0.80 |
| Maximum | 64.70 | 45.23 | 15.88 |
| Number NOx Stack Exhaust Periods > 11 ppmvd | N/A | 940 | 181 |
| Percentage of 15-minute periods > 11 ppmvd | N/A | 4.4% | 0.9% |

Notes:
1) Concentrations are presented in parts per million by volume dry (ppmvd) at 15% $O_2$.
2) NOx CEMS data is based on the 15-minute average NOx concentrations from June 8, 2010 through March 31, 2011.
3) N/A indicates not applicable

**Table 3-13:**
## Ammonia Concentration Sampling Event Summary

| Date | Engine Load (%) | Free $NH_3$ Field Measurement[1] (ppmv) | Total $NH_3$ Calculated Value[2] (ppmv) | Free $NH_3$ SCAQMD Method 207.1 (ppmv) |
|---|---|---|---|---|
| 4/7/2010 & 4/8/2010 | 65 | <MDL | 1.66 | 0.12 |
| | 90 | | | 0.18 |
| | 105 | | | 0.43 |
| 4/21/2010 | 110 | <MDL | 0.09 | N/A |
| 4/29/2010 | 90 | <MDL | 0.00 | N/A |
| 5/6/2010 | 94 | <MDL | 2.18 | N/A |
| 5/19/2010 | 100 | <MDL | 2.54 | N/A |
| 6/29/2010 | 100 | <MDL | 0.97 | N/A |
| 7/28/2010 | 100 | <MDL | 0.63 | N/A |
| 8/12/2010 | 95 | <MDL | 2.50 | N/A |
| 11/4/2010 | 100 | <MDL | 4.95 | N/A |
| 1/12/2011 | 100 | <MDL | 0.32 | N/A |
| 2/24/2011 | 100 | <MDL | 0.09 | N/A |
| 5/10/2011 | 70 | <MDL | 1.12 | 0.37 |
| | 90 | | 1.60 | 0.31 |
| | 110 | | 3.12 | 0.38 |

Notes:
1) Free ammonia field measurements are taken using MDL to 2.5-3 ppm range and 2 to 30 ppm range Draeger® tubes.
2) Total ammonia was determined based on the theoretical calculation which uses NOx inlet and NOx outlet of the catalytic oxidizer/ SCR system and the urea injection rate. The calculated value reported is based on the 15-minute block averages from the CEMS for the time period when the exhaust gas sample was taken for the field measurement. No correction factor was applied.
3) <MDL: below Method Detection Limit.
4) N/A indicates not applicable. No data was taken using Method 207.1 during these field measurement events.

**Table 3-14:**
## Catalytic Oxidizer /SCR System Performance Proposal

| | |
|---|---|
| Urea usage estimate (32.5% urea solution) @ 80% NOx reduction | 1.1 gallons/hour |
| Estimated pressure drop across catalytic oxidizer using a 4040 arrangement with one layer of standard depth (~ 3.5") catalyst elements @ 200 CPSI = A | 0.7 in. wc. |
| Estimated pressure drop across SCR converter using a 4040 arrangement with two layers of standard depth (~ 3.5") catalyst elements @ 200 CPSI = B | 1.4 in. wc. |
| Estimated pressure drop across 12 foot long mixing duct with one static mixer installed = C | 1.9 in. wc. |
| Total system pressure loss estimate (includes loss through oxidation converter, SCR converter, expansion joint, and mixing duct) using 4040 oxidation catalyst and two layers of 4040 SCR catalyst (A + B + C) | 4.0 in. wc. |
| Estimated pressure drop across one additional layer (~ 3.5") of either catalytic oxidizer or SCR elements that are 200 CPSI | 0.7 in. wc. |
| Additional system pressure drop loss estimate if an additional layer (~ 3.5") of 100 CPSI catalyst in the 4040 housing is employed | 0.4 in. wc. |
| Additional system pressure drop loss estimate if an additional layer (~ 2") of 200 CPSI catalyst in the 4040 housing is employed | 0.3 in. wc. |

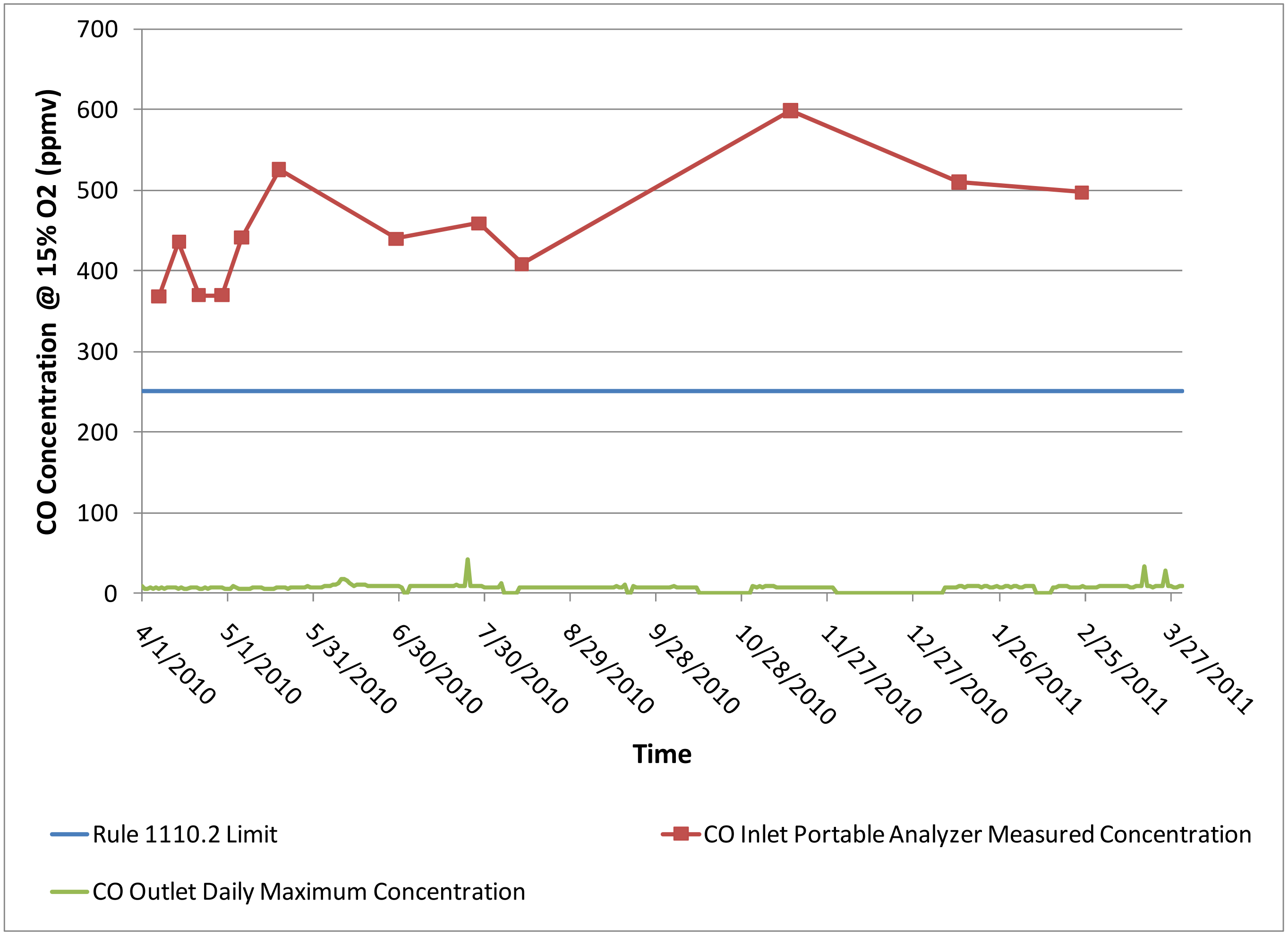
Notes: Estimates provided by Johnson Matthey in their system proposal, dated May 8, 2009.

**Table 3-15:**
**Catalytic Oxidizer /SCR System Performance Data**

| | Unit | Average Value |
|---|---|---|
| Urea Injection Rate | gallon per hour | 0.62 |
| Catalytic Oxidizer Inlet Temperature | °F | 781 |
| Catalytic Oxidizer Outlet Temperature | °F | 779 |
| Catalytic Oxidizer Differential Pressure | in. wc. | 0.3 |
| SCR Inlet Temperature | °F | 796 |
| SCR Outlet Temperature | °F | 756 |
| SCR Differential Pressure | in. wc. | 1.0 |

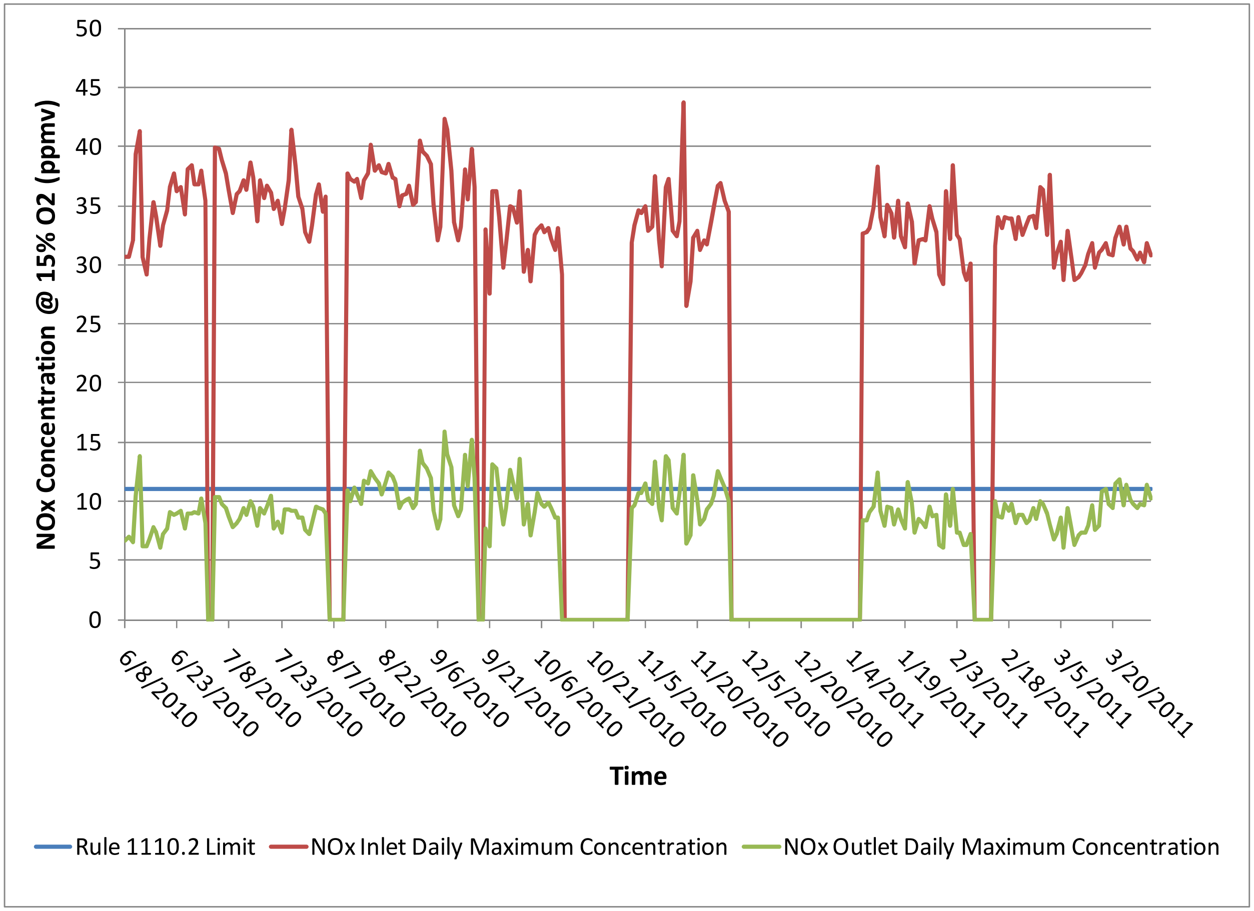
Notes:
1) Estimates are provided by the data logger located inside of the urea injection cabinet for the period of April 1, 2010 through November 4, 2010 and January 1, 2011 through February 24, 2011.
2) The data have been validated to remove periods where the engine was offline, as indicated when urea injection is offline, temperatures in the catalysts cool and NOx inlet value drop.

**Figure 3-1: Catalytic Oxidizer Inlet and Outlet CO Concentration**



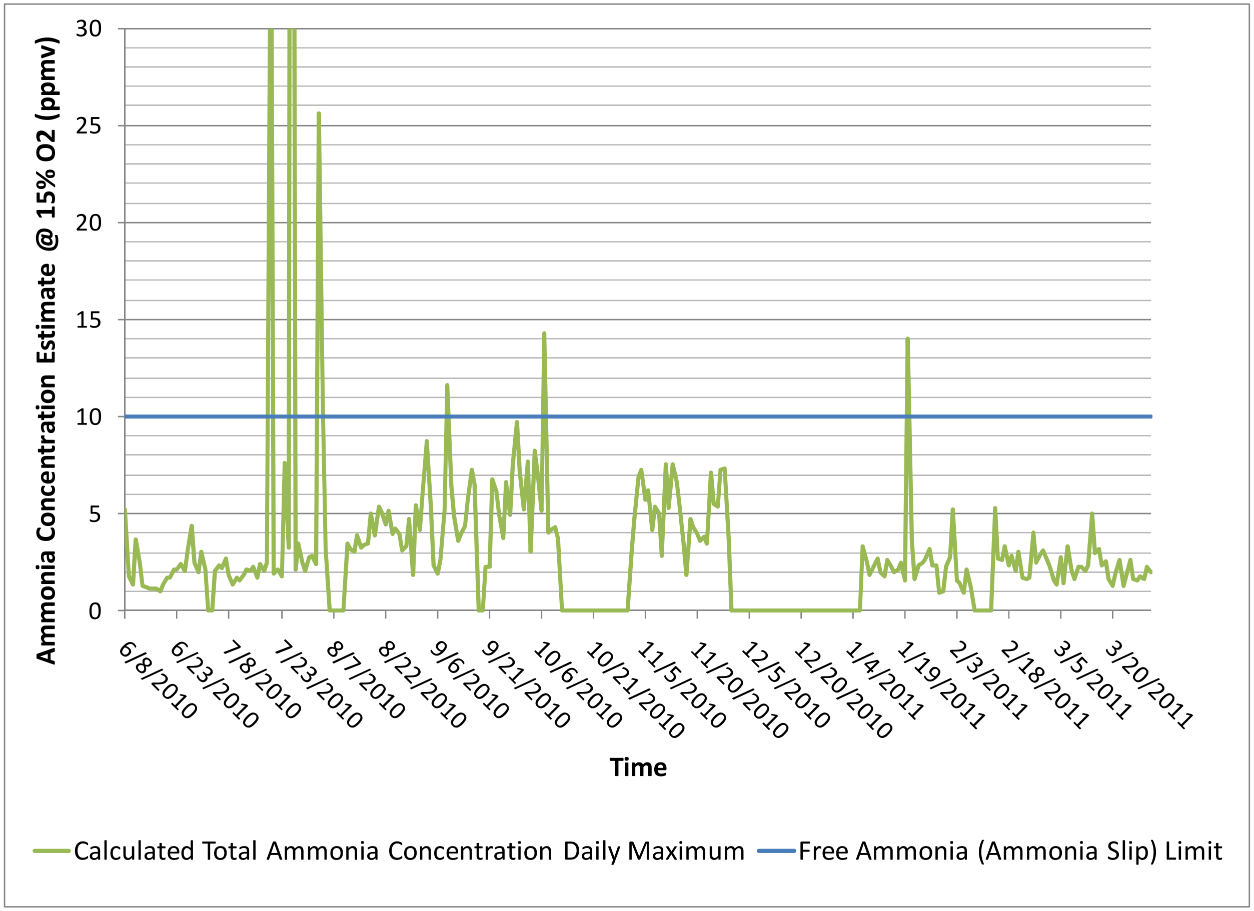

Notes:
1) The first 30 minutes after start-up of the engine are exempt from amended Rule 1110.2. Data was excluded where NOx at the stack exhaust exceeded 11 ppmvd during engine start-up.
2) CEMS values shown are maximum values for each calendar day and may not all occur at the same time as the portable analyzer measurement.
3) Spikes where inlet and outlet NOx concentrations drop to 0 ppmv occur when the engine is offline.

**Figure 3-2: Selective Catalytic Reduction Inlet and Outlet NOx Concentration**




Notes:
1) The first 30 minutes after start-up of the engine are exempt from amended Rule 1110.2. Data was excluded where NOx at the stack exhaust exceeded 11 ppmvd during engine start-up.
2) Data was excluded where NOx at the stack exhaust exceeded 11 due to system adjustments to the urea injection system.
3) Data was excluded where operational issues occurred from 7/1/10-7/4/10, 12/29/10-1/4/11, 3/14/11, 3/17/11, and 3/22/11.
4) Values shown are maximum values for each calendar day and may not all occur at the same time within the day.
5) Spikes where inlet and outlet NOx concentrations drop to 0 ppmv occur when the engine is offline.

**Figure 3-3: Selective Catalytic Reduction Estimated Total Ammonia Concentration**




Notes:
1) The first 30 minutes after start-up of the engine are exempt from amended Rule 1110.2. Data were excluded where NOx at the stack exhaust exceeded 11 ppmvd during engine start-up.
2) Data were excluded where the SCR system was offline due to system adjustments to the urea injection system.
3) Data were excluded where operational issues occurred from 7/1/10-7/4/10, 12/29/10-1/4/11, 3/14/11, 3/17/11, and 3/22/11.
4) Values shown are maximum 15-minute values for each calendar day.
5) Spikes where inlet and outlet ammonia concentrations drop to 0 ppmv occur when the engine is offline.
6) Ammonia concentration values reported on July 20, 2010 and July 26, 2010 occurred within one hour of an engine shutdown or startup and were not part of the 30-minute exemption from amended Rule 1110.2.

# 4. Cost Effectiveness Analysis

A cost analysis for the implementation of the DGCS and Cat Ox/SCR systems at Plant 1 Engine 1 was performed. The cost analysis was developed for one digester gas cleaning vessel, with an approximate capacity of 9,900 lbs of carbon media and associated piping, and one Cat Ox/SCR system with platform installation.

## 4.1. Capital and Operation & Maintenance Costs

The capital project budget includes the following construction costs: equipment; installation; mechanical; structural; electrical; site/architectural; instrumentation; and material sales tax; as well as the construction contractor’s expenses, such as contractor overhead, profit, mobilization, bonding, and insurance. For capital cost the following assumptions apply:

- The construction cost subtotal is time dated for June 2009 and based on the pilot test construction contract price, including change orders.
- The equipment cost is time dated for June 2009 and based on the pilot test costs of the following equipment: one Cat Ox/SCR system with urea injection control cabinet for Plant 1 Engine 1; one digester gas cleaning vessel with inlet, outlet, and bypass piping sized to treat 100 percent of the digester gas for the Plant 1 cogeneration facility; one NOx probe and umbilical sample line from the Engine 1 exhaust to the CEMS panel in the control room; and seven expansion joints for the engine exhaust ductwork.
- Project design and engineering is assumed to be 15% of the total construction and equipment cost.
- The annualized total capital project budget is based on a 20-year evaluation period and 4.0 percent annualized rate, as set forth in the SCAQMD July 9, 2010 Board Meeting Minutes, Attachment B: Assessment of Available Technology for Control of NOx, CO and VOC Emissions from Biogas-Fueled Engines – Interim Report.

Annual O&M costs associated with operating the digester gas cleaning system and Cat Ox/SCR system includes the following components:

- Annual additional electrical cost;
- Annual carbon media replacement costs;
- Oxidation and SCR catalyst replacement costs;
- Annual urea usage costs;
- Annual equipment maintenance costs;
- Periodic siloxane, VOC, and $H_2S$ testing;

- The reduction in O&M costs due to the use of clean digester gas was considered. Such reduction in O&M costs includes a reduction in frequency of major maintenance interval service and maintenance shutdowns related to siloxane compounds present in the digester gas.
- The reduction in annual emissions fees for NOx, VOC, CO, and formaldehyde based on the estimated emissions reductions realized from the engine exhaust control system was considered.

The assumptions related to the O&M costs are the following:

- Annual operating hours of a single engine at Plant 1 is estimated to be 6,000 hours.
- The change-out of the carbon media for the digester gas cleaning system is estimated to be approximately $40,000 per change-out. The change-out frequency with three engines operating at Plant 1 at 6,000 annual operating hours is approximately three (3) times per year. The total annual cost of carbon media for three engines at 6,000 annual operating hours is $120,000 per year. Therefore, the cost for carbon media for a single engine is approximately $40,000 per year.
- The replacement of the sixteen catalytic oxidizer media blocks and thirty-two SCR catalyst media blocks is estimated to take place once every three years for each engine. Although the Cat Ox/SCR system demonstrated performance for one year during the pilot testing period, it is assumed that the media will perform for three years based on the vendor warranty of 16,000 operating hours. Assuming that each engine operates for 6,000 hour per year, the engine should reach 16,000 operating hours in 2 years and 8 months. The costs of each catalytic oxidizer media block and SCR catalyst media block are $3,450 and $1,850, respectively.
- Urea cost is assumed to equal $4.50 per gallon, including tax, at an average rate of 0.7 gallons per hour for 6,000 annual operating hours.
- Equipment maintenance and testing is assumed to equal $5,000 per year for annual maintenance of the SCR urea injection system, $5,400 per year for siloxane testing ($600 per sample, 3 samples per change out, and 3 change outs per year), and $3,000 per year for VOC and $H_2S$ sampling.
- Annual reduced engine maintenance cost using cleaned digester gas, assumed to equal $130,641 for three engines operating at 6,000 hours annually. Therefore, the approximate savings per engine is approximately $43,547 per year as estimated by OCSD. Currently, the three engines at Plant 1 are consuming all of the digester gas produced by the facility. Therefore, although the annual cost of maintenance is decreased, the total operating time of each engine will remain the same.
- Calculation of emissions reductions for NOx, VOC, and CO is provided in Scenario 2 in Section 4.2 below. Scenario 2 assumed that the uncontrolled NOx, VOC, and CO emissions were based on the results from the 2011 Annual Compliance Test for Engines 2 and 3. The controlled emissions were based on the Rule 1110.2 limits of 11 ppmv for NOx and 30 ppmv for VOCs, and the pilot testing results of 15 ppmv for CO. Fees per ton of NOx, VOC, and CO are assumed to be $270.26, $576.75, and

$3.57, respectively, based on the Annual Emission Report provided by the OCSD dated February 23, 2011.

- The uncontrolled emissions of formaldehyde were based on the results of the 2009 Annual Compliance Test for Engine 3 of 1.4 lb/hr. The controlled emissions of formaldehyde were based on the results of the 2011 Annual Compliance Test for Engine 1 of 0.069 lb/hr. It is assumed that the annual operating hours of a single engine at Plant 1 is 6,000 hours. Therefore, formaldehyde emissions reduction is 4.13 tons per year. The fee per ton of formaldehyde is assumed to be $800.00 based on the Annual Emission Report provided by the OCSD dated February 23, 2011.
- Annual O&M costs do not include the cost of ammonia sampling because it is assumed that ammonia sampling is part of the annual compliance test. The estimated ammonia sampling cost is $2,500 for one sampling event per year using SCAQMD Method 207.1. The annual cost of weekly ammonia testing using Draeger® tubes or similar colorimetric tubes is assumed to equal $300.

The capital cost and annual O&M costs for a single engine is presented in Table 4-1.

## 4.2. Unitized Cost of Carbon Media and Emissions Reduction

The cost of implementation of the DGCS and Cat Ox/SCR systems can be unitized as a cost per cubic foot of digester gas treated or as a cost per ton of NOx and VOC reduced in the emissions. The following summarizes these metrics for evaluating costs.

### 4.2.1. Cost for Volume of Digester Gas Treated

A metric for evaluating the cost of the DGCS is the cost per cubic foot of digester gas treated. This metric is based on the frequency of the carbon media change-out as well as the cost per change-out. The digester gas volume that passed through the catalyst during the pilot test ranged from 146 MMcf to 169 MMcf. The cost of each carbon media change-out is assumed to be approximately $40,000. Therefore, the cost per treated digester gas ranges between $237/MMcf and $274/MMcf. The capacity of the digester gas cleaning vessel is 9,900 pounds of carbon media. Therefore the media per volume of treated digester gas ranges between 59 lbs/MMcf and 68 lbs/MMcf. Note that these are conservative estimates. The pilot test only utilized a single digester gas cleaning vessel as opposed to a lead/lag configuration in which two vessels, a lead vessel followed by a second lag vessel, are used. Therefore, the carbon media was replaced more frequently than necessary to prevent potential breakthrough of siloxane compounds that may foul the catalyst. In a lead/lag configuration, the volume of gas treated between change-outs can be extended since breakthrough can be allowed to occur in the lead vessel because any siloxane compounds would be removed in the lag vessel.

### 4.2.2. Cost for Reductions in NOx and VOCs, and CO Emissions

A metric for evaluating the cost effectiveness of the Cat Ox/SCR system is cost per ton of NOx, VOC, and CO removed by the system. Based on the total annualized cost per engine, two scenarios for estimating NOx, VOC, and CO emissions reduced were developed. The following are the assumed uncontrolled and controlled concentrations for the two scenarios:

**Scenario 1**

- Uncontrolled concentrations are based on the current permit limits of 45 ppmv of NOx, 209 ppmv of VOCs, and 2,000 ppmv of CO, each at 15% $O_2$.
- Controlled emissions are based on the future Rule 1110.2 limits of 11 ppmv of NOx and 30 ppmv of VOCs, each at 15% $O_2$. Controlled emissions for CO are based on 15 ppmv because the Cat Ox/SCR system consistently reduced CO emissions well below the Rule 1110.2 limit of 250 ppmv. The concentration of 15 ppmv provides a factor of safety of 2 over the average CO concentration of 7.5 ppmv. The factor of safety gives credit for projected emissions reduction, but allows for reduced efficiency as the catalyst approaches the end of its lifecycle, prior to replacement.

**Scenario 2**

- Uncontrolled concentrations from the 2011 Annual Source Test Report are 31 ppmv of NOx, 97 ppmv of VOCs, and 371 ppmv of CO at 15% $O_2$ for Plant 1 (Engines 2 and 3).
- Controlled emissions are based on the future Rule 1110.2 limits of 11 ppmv of NOx and 30 ppmv of VOCs, each at 15% $O_2$. Controlled emissions for CO are based on 15 ppmv because the Cat Ox/SCR system consistently reduced CO emissions well below the Rule 1110.2 limit of 250 ppmv. The concentration of 15 ppmv provides a factor of safety of 2 over the average CO concentration of 7.5 ppmv. The factor of safety gives credit for projected emissions reduction, but allows for reduced efficiency as the catalyst approaches the end of its lifecycle, prior to replacement.

The assumptions used for each scenario were:

- Annual operating hours of a single engine at Plant 1 is estimated to be 6,000 hours;
- Exhaust flowrates are based on high load; and
- VOCs emissions are calculated as methane.

Table 4-2 provides a summary of the cost effectiveness for the two scenarios for one engine at Plant 1. The cost effectiveness in terms of dollars per ton of NOx and VOCs reduced for Scenarios 1 and 2 was $7,987 and $17,585, respectively. The cost effectiveness in terms of dollars per ton of CO reduced for Scenarios 1 and 2 was $363 and $3,546, respectively. Note that the cost effectiveness for CO is conservative since the annualized cost is based on the entire system including the SCR and urea injection system.

**Table 4-1:**
**Estimated Capital and O&M Costs for Plant 1 Engine 1**

| **Capital Cost** | **Plant 1 Engine 1[1]** |
|---|---|
| Equipment (Cat Ox/SCR, DGCV, CEMS, Expansion Joints) | $708,000 |
| **Labor and Contractor Cost[2]** | |
| Bonding/Insurance | $21,272 |
| Mobilization | $56,748 |
| Prime Contractor Labor and Construction (i.e. concrete & rebar, piping, fittings, valves, installation & start-up, management, etc.) | $765,723 |
| Steel Subcontractor (i.e. structural steel, miscellaneous metal, handrail, grating) | $249,941 |
| Insulation Subcontractor | $82,879 |
| Electrical Subcontractor (i.e. wiring, conduit, grounding, etc.) | $76,311 |
| Painting Subcontractor | $28,655 |
| Labor and Contractor Cost Subtotal (including contractor markups for overhead, profit, mobilization, bonding, insurance) | $1,281,529 |
| Construction Subtotal (June 2009 dollars) | $1,989,529 |
| Project Design and Engineering (15% of construction subtotal) | $298,429 |
| Total Capital Cost | $2,287,958 |
| Annualized Capital Cost (4 % annual rate, 20 years) | $168,352 |
| | |
| **Annual O&M Cost for 1 Engine (operating 6,000 hrs/yr)[3]** | **Plant 1 Engine 1** |
| Carbon Media Replacement | $40,000 |
| Catalyst Replacement | $38,133 |
| Urea Cost | $18,900 |
| Electrical Cost | $1,200 |
| Equipment Maintenance and Testing | $13,400 |
| Reduced Engine Maintenance | $(43,547) |
| Reduced Emission Fees | $(9,136) |
| Annual O&M Cost per Engine | $58,950 |
| **Total Annual Capital and O&M Cost for 1 Engine** | **Plant 1 Engine 1** |
| **Total Annualized Cost per Engine** | **$227,302** |

Notes:
1) Engine Size: 2,500 kW/3,471 bhp
2) Subcontractor costs include a 10% prime contractor markup.
3) Assumptions for the basis of O&M costs is provided in Section 4.1.

**Table 4-2:**
**Cost per Ton NOx and VOC Emissions Reduced at Plant 1 Engine 1**

| **Capital Cost** | **Plant 1 Engine 1** |
|---|---|
| Annualized Capital Cost (4 % annual rate, 20 years) | $168,352 |
| Annual O&M Cost per Engine[1,2] | $58,950 |
| **Total Annualized Cost per Engine** | **$227,302** |
| | |
| **Scenario 1** | **Plant 1 Engine 1** |
| Uncontrolled NOx – Current Permit Limit (ppmv) | 45 |
| Controlled NOx – Future Rule 1110.2 Limit (ppmv) | 11 |
| Uncontrolled VOC – Current Permit Limit (ppmv) | 209 |
| Controlled VOC – Future Rule 1110.2 Limit (ppmv) | 30 |
| Uncontrolled CO – Current Permit Limit (ppmv) | 2,000 |
| Controlled CO (ppmv)[3] | 15 |
| NOx Reduction (ton/yr) | 10.05 |
| VOC Reduction (ton/yr) | 18.41 |
| CO Reduction (ton/yr) | 357.21 |
| **Cost Effectiveness ($/ton of NOx and VOC reduced)** | **$7,987** |
| **Cost Effectiveness ($/ton of CO reduced)** | **$636** |
| | |
| **Scenario 2** | **Plant 1 Engine 1** |
| Uncontrolled NOx – 2011 Source Testing Data (ppmv) | 31 |
| Controlled NOx – Future Rule 1110.2 Limit (ppmv) | 11 |
| Uncontrolled VOC (ppmv) | 97 |
| Controlled VOC – Future Rule 1110.2 Limit (ppmv) | 30 |
| Uncontrolled CO – 2011 Source Testing Data (ppmv) | 371 |
| Controlled CO (ppmv)[3] | 15 |
| NOx Reduction (ton/yr) | 6.03 |
| VOC Reduction (ton/yr) | 6.89 |
| CO Reduction (ton/yr) | 64.10 |
| **Cost Effectiveness ($/ton of NOx and VOC reduced)[4]** | **$17,585** |
| **Cost Effectiveness ($/ton of CO reduced)[4]** | **$3,546** |

Notes:
1) Engine Size: 2,500 kW/3,471 bhp
2) Annual Operating Hours: 6,000 hours/year
3) Controlled emissions for CO are based on 15 ppmv because the Cat Ox/SCR system consistently reduced CO emissions well below the Rule 1110.2 limit of 250 ppmv. The concentration of 15 ppmv provides a factor of safety of 2 over the average CO concentration of 7.5 ppmv.
4) Cost effectiveness of NOx and VOC reduced and CO reduced are calculated separately. The cost effectiveness of NOx and VOC is equal to the annualized cost per engine divided by the sum of NOx and VOC tons per year reduced. The cost effectiveness of CO is equal to the annualized cost per engine divided by the CO tons per year reduced and does not take NOx or VOC reduction into consideration.

# 5. Conclusions and Recommendations

In order to evaluate if the amended Rule 1110.2 limits could be met for their digester gas-fired IC engines, OCSD proposed to perform a pilot study on Engine 1 at Plant 1. In previous studies, OCSD had identified a catalytic oxidizer and SCR system along with a DGCS as the most feasible technology to lower air toxic emissions and to meet the new lower emissions limits. Because SCAQMD recognized that the emission limits in the new Rule 1110.2 were "technology-forcing," they provided a grant to OCSD to support the pilot study at Plant 1 Engine 1 as part of a Rule 1110.2 technology assessment study to determine if cost-effective and commercial technologies are available to comply with the new lower emission limits. The 12-month pilot study at Plant 1 evaluated the effectiveness of the control systems to meet Rule 1110.2 limits.

## 5.1. System Performance

The DGCS system, in general, removed siloxanes from the digester gas to below MDL levels and significantly reduced sulfur compounds and VOCs successfully reducing catalyst masking which should lead to extended catalyst life. Additional benefits of the contaminant removal were significant improvements in engine maintenance requirements, and lower O&M costs. The use of cleaned digester gas resulted in much less frequent maintenance requirements for the engine, including longer time intervals between spark plug changes and major maintenance events.

There were no notable back pressure effects on engine performance due to the installation of the Cat Ox/SCR system with a DGCS during the pilot test. The system design back pressure for the Cat Ox/SCR system and additional exhaust ductwork was estimated to not exceed 9 in. wc. per the engine manufacturer's recommendations. Based on the data monitored during the pilot test, the average differential pressure through the catalytic oxidizer and SCR systems are approximately 0.3 and 1.0 in. wc, respectively.

The combined Cat Ox/SCR system with digester gas cleaning evaluated in the pilot study resulted in significant reductions in CO, VOC, and NOx emissions from the digester gas fired IC engine at Plant 1 providing substantial air quality benefits from this system. In addition, NOx and CO, along with VOCs (as NMNEOCs) are considered indirect greenhouse gases, affecting tropospheric ozone and methane levels.

## 5.2. Comparison to Rule 1110.2 Limits and Other Criteria

- The average NOx concentration at the stack exhaust after the pilot study Cat Ox/SCR system was approximately 7 ppmv, below the 11 ppmv under amended Rule 1110.2. The lowest NOx stack exhaust concentration met consistently under all valid conditions was 16 ppmv. While there were some periods when the NOx stack exhaust concentration was above 11 ppmv; after screening these periods to eliminate unusual operational events or start-up conditions, 181 periods out of 21,285 total operating periods (approximately 5,321 hours) remained as valid periods where the NOx stack exhaust concentration was above the new Rule 1110.2 limit. These periods occurred during 61 separate events and accounted for less than 0.9% of the total measurement periods during the pilot study.

- Free ammonia (ammonia slip), the result of excess urea injection in the SCR system, was below 0.5 ppmv using SCAQMD compliance sampling methods and below the MDL using Draeger® tubes over the course of the pilot study. The total ammonia calculation method, unlike the measurement methods for free ammonia, did predict low levels of total ammonia. It was noted that the total ammonia calculation method estimates did not include the use of a project-specific correction factor, CF, which could be used to account for secondary reactions that would consume ammonia, thus bringing the total ammonia calculation method estimates more in line with the measurements of free ammonia.
- The maximum CO concentration at the stack exhaust (42.2 ppmv) was well below the amended Rule 1110.2 emission limit of 250 ppmv.
- The maximum VOC concentration at the stack exhaust (4.95 ppmv) was consistently well below the 30 ppmv in amended Rule 1110.2.

Therefore, with the exception of a relatively limited number of periods when the NOx stack exhaust concentration was above the new amended Rule 1110.2 limit, the combined Cat Ox/SCR system equipped with a DGCS was able to meet the new emission limits.

## 5.3. Cost Effectiveness

The total capital costs to design, procure, and install a digester gas cleaning vessel to clean all the digester gas to the Plant 1 engines, and a Cat Ox/SCR system with auxiliary equipment for Engine 1 is estimated to be $2,300,000. The annual O&M cost for these systems at Plant 1 is approximately $59,000. Assuming a 20-year lifespan, the total annualized cost (capital cost plus O&M) for the DGCS and Cat Ox/SCR systems for Plant 1 Engine 1 is $227,000.

The cost effectiveness analysis (based on dollars per ton of NOx, VOC and CO emissions reduced) was developed for two scenarios: Scenario 1 assumed that the uncontrolled emissions were based on permit limits (i.e., 45 ppmv, 209 ppmv, and 2,000 ppmv, respectively), and Scenario 2 assumed that the uncontrolled emissions were based on the results from the 2011 Annual Compliance Test for Engines 2 and 3. Both scenarios assumed that the controlled emissions were based on the Rule 1110.2 limits of 11 ppmv for NOx, 30 ppmv for VOCs, and the pilot testing results of 15 ppmv for CO. Under these assumptions, the cost effectiveness estimates for Scenarios 1 and 2 are $7,987 and $17,585, respectively, per ton of NOx plus VOCs reduced. The cost effectiveness estimates for Scenarios 1 and 2 are $636 and $3,546, respectively, per ton of CO reduced.

Note that the cost effectiveness for CO is conservative since the annualized cost is based on the entire system including the SCR and urea injection system. The annualized cost and emissions reduced calculations were based on operating each engine for a maximum of 6,000 hours per year.

## 5.4. Recommendations

SCR systems similar to the Johnson Matthey system used in the present pilot study are commercially available and have successfully demonstrated NOx control for single fuels, such as natural gas. However, based on previous source testing data, the NOx concentration is higher for natural gas than digester gas at a given load; therefore, there is a potential for variations in NOx concentration at the inlet to the SCR system at a given load due to the varying fuel blend in biogas-fueled engines. Since the urea injection rate can only be established based on engine load and not inlet NOx concentration, it is difficult to maintain a targeted NOx limit at the stack exhaust using this type of SCR system.

NOx concentrations in the stack exhaust were above the amended Rule 1110.2 NOx limit of 11 ppmv for a small number of sampling periods during the pilot study. These periods where the NOx stack exhaust concentration was over 11 ppmv may indicate that this limit is too conservative, especially for biogas-fueled and dual-fueled engines where a steady SCR control efficiency is difficult to maintain. Recommendations regarding the new amended Rule 1110.2 NOx limit of 11 ppmv are as follows:

1. Given the variations in the engine load and urea injection rate mapping requirements for the digester gas-fired IC engine, using the 15-minute block average for compliance with the NOx emission limit may also be too restrictive, and a longer averaging time may be more appropriate for biogas-fired engines. Alternatively, allowing a limited number of excursions above the 11 ppmv for biogas-fueled engines, for example, 5% of the total annual continuous (i.e., 15-minute averaging periods) NOx data, to account for the difficulty in accurately mapping the urea injection rate to control NOx outlet concentration, may also be warranted.

2. In April 2011, after the official pilot testing period concluded, a Johnson Matthey technician adjusted the urea injection rate curve to 1) expand the curve to a maximum of 125% engine load and 2) to increase the urea injection rate at high engine loads. The increase in urea injection rate should accommodate for the increased NOx production when the engine combusts a fuel blend with a higher percentage of natural gas. Further observation will be required to confirm if these adjustments will lead to a reduction in the number of periods where stack exhaust NOx outlet concentration is above 11 ppmv.

Further sampling of the exhaust emissions can be performed to establish a correction factor for the estimated total ammonia calculation method and to confirm that the SCR system does not produce measureable free ammonia. Recommendations regarding the estimated total ammonia calculation method are as follows:

3. The presence of sulfur dioxide and sulfur trioxide in the exhaust gas before the SCR, and ammonium sulfate and ammonia bisulfate in the exhaust gas after the SCR, can indicate secondary reactions between the ammonia and sulfur compounds in the exhaust gases taking place due to the injection of urea. The correction factor, CF, can be used in the estimated total ammonia calculation method to account for these reactions, thus improving this calculation for estimating free ammonia.

4. Although the pilot study data indicates that there is minimal, if any, free ammonia due to the SCR system, it is recommended that the OCSD perform additional and routine testing for free ammonia during varying loads and fuel blends over a period of time to accumulate data corroborating that the SCR system does not produce measurable free ammonia under all operating conditions for a given mapped urea injection versus engine load set point.

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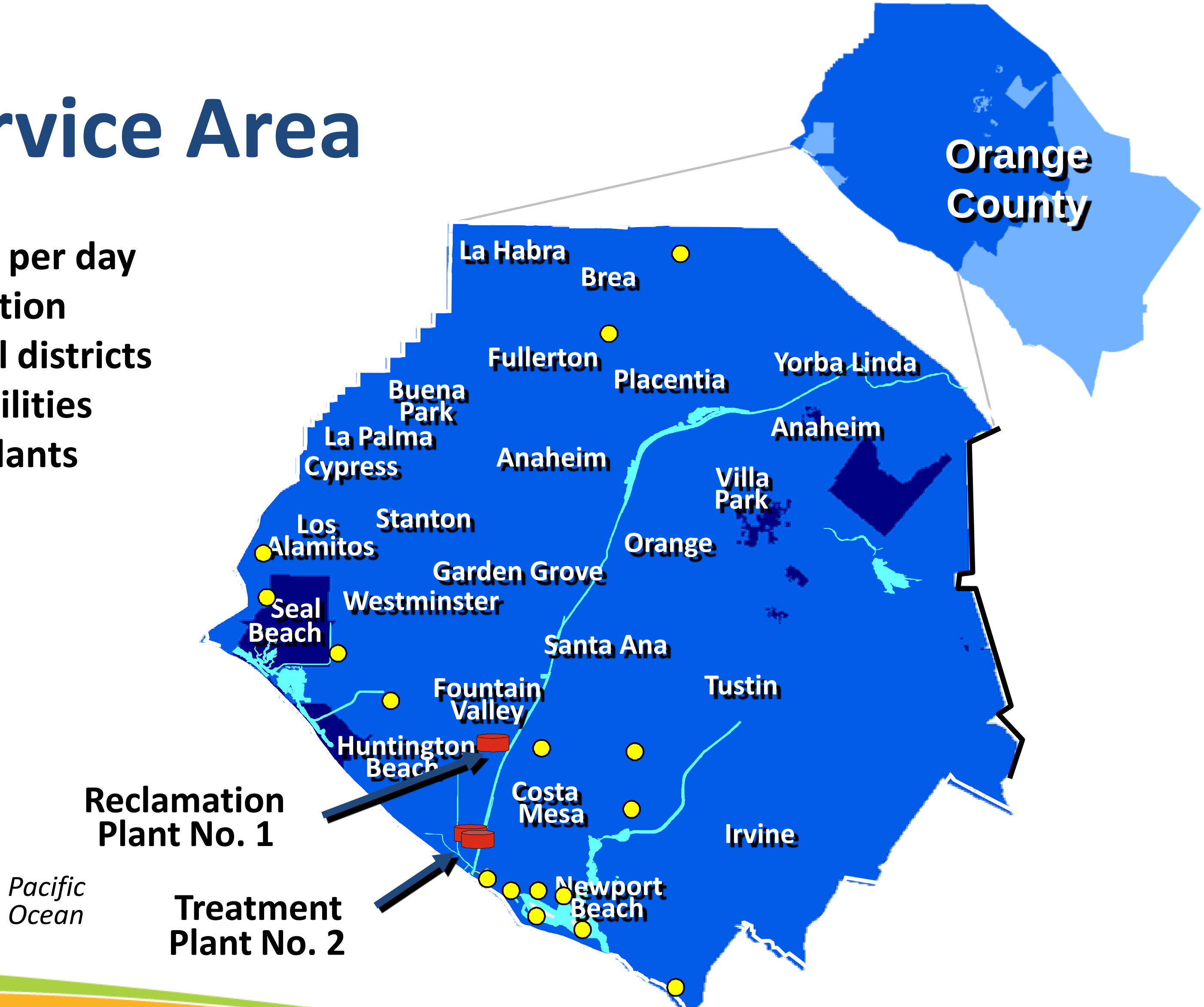
# Orange County Sanitation District Technology Demonstration Project Update

Lisa Rothbart, PE
Environmental Supervisor
Orange County Sanitation District

# OCSD Service Area

471 square miles
207 million gallons per day
2.5 million population
21 cities, 3 special districts
15 pumping facilities
2 treatment plants



# Central Power Generation Facilities

**<u>Plant No. 1 – Fountain Valley</u>**

- 3 identical IC engines
- 3471 hp each; lean burn
- 2500 kW generator
- **Total nameplate capacity: 7.5 MW**

**<u>Plant No. 2 – Huntington Beach</u>**

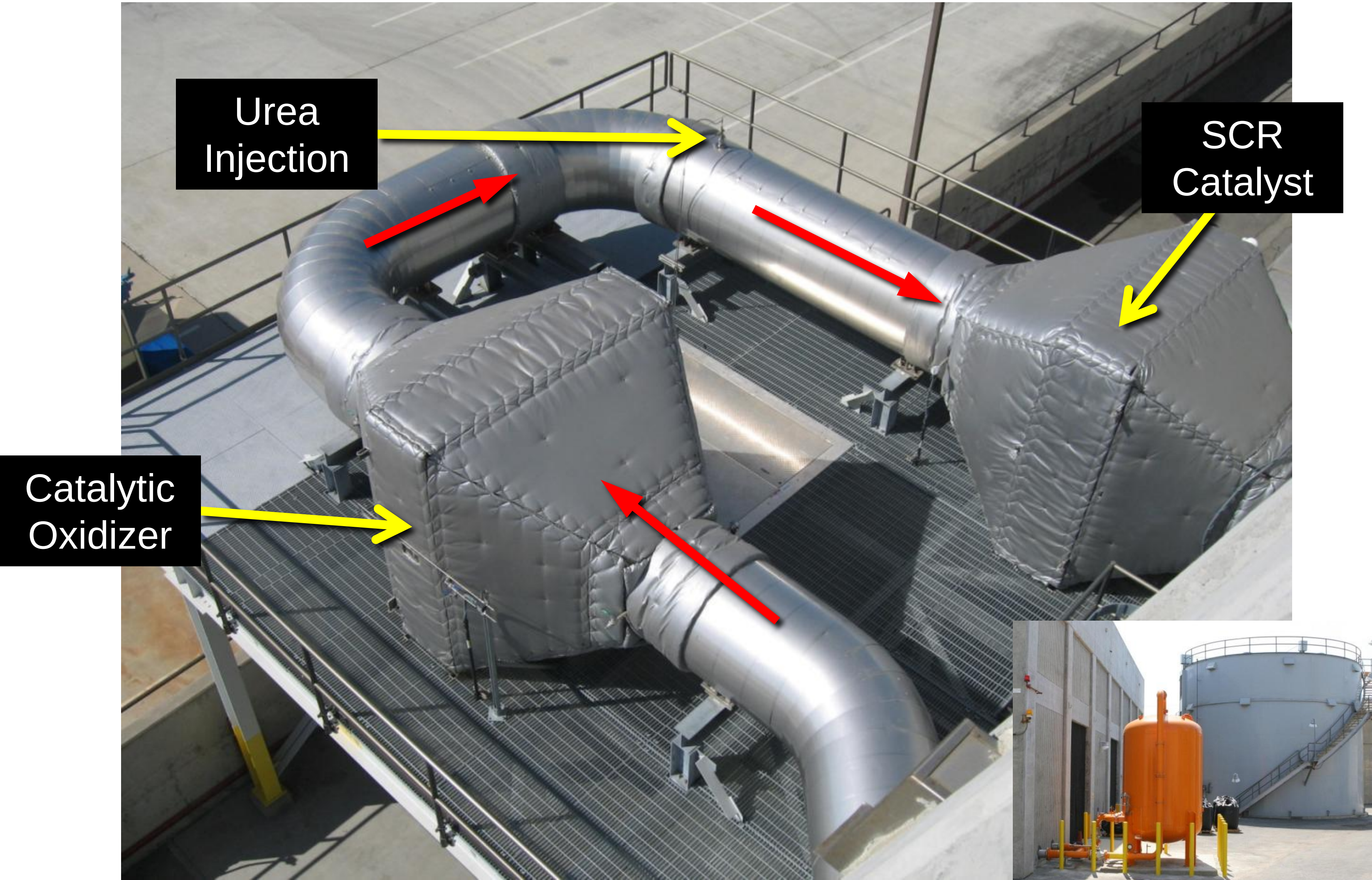
- 5 identical IC engines
- 4166 hp each; lean burn
- 3000 kW generator
- 1 MW steam turbine
- **Total nameplate capacity: 16 MW**

***Both plants combined: 1.4 billion cubic feet of digester gas produced in 2013***

# One-Year Technology Demonstration

- ✓ *Demonstration monitoring conducted from April 1, 2010 to March 31, 2011*
- ✓ *Over 21,000 data points recorded (more than 5000 engine operating hours*
- ✓ *Final report submitted to SCAQMD in July 2011*

# Catalytic Oxidizer/SCR System

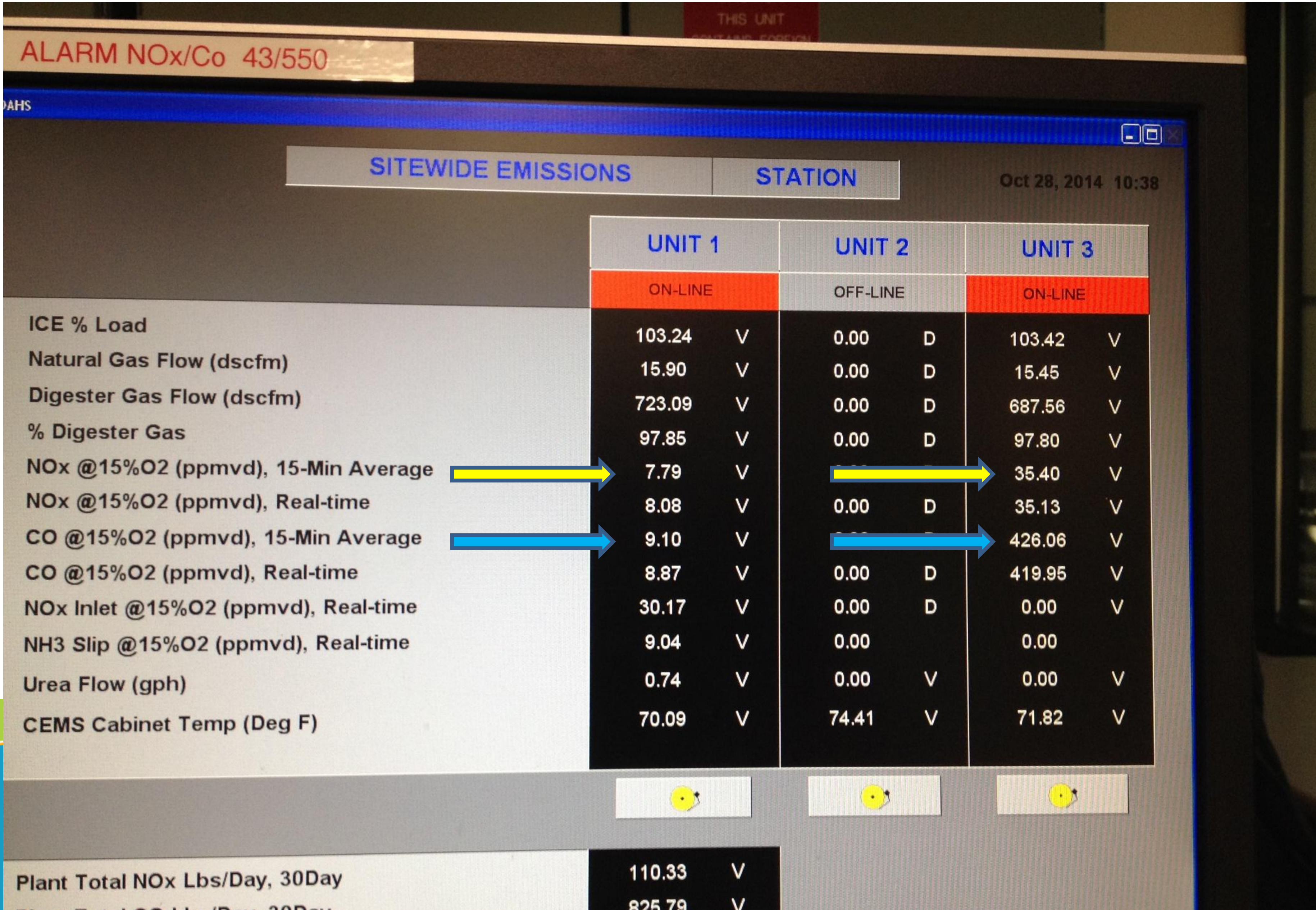


# Technology Demonstration Project (April 1, 2010 – March 31, 2011) Emissions Levels Achieved

| Pollutant | Engine Exhaust w/o Catalysts (ppmv) | Engine Exhaust With Catalysts (ppmv) | Rule 1110.2 limit (ppmv) |
|---|---|---|---|
| $NO_x$ | 31 | **7.2** (0.8 to 21.8) | 11 |
| CO | 452 | **7.5** (4.0 to 42.2) | 250 |
| VOC | 97 | **3.6** (0.73 to 5.42) | 30 |

15-minute averages. Validated data only. Excludes exceedances during engine start-up (30 minutes) and due to operational issues/systems adjustments.

# CEMS Comparison – October 28th 2014



# Recent CEMS Data

*Nearly  30,000 operating hours later* – still using original catalysts

May 2014 – October 2014:

8.2 ppm $NO_X$

8.4 ppm CO

5.5 ppm $NH_3$ slip

11.5 ppm VOC (not CEMS)

# Full Implementation: Project J-111

- Gas cleaning units in primary/polishing configuration
- Construction RFP issued Dec 27th 2013
- OCSD Board of Directors approved contract April 23rd 2014
- Notice to Proceed issued May 27, 2014

# Current Construction

# All Engines Will Not Meet Rule 1110.2 Deadline

- January 8, 2016
  - One engine complete at Plant 1
  - Two engines complete at Plant 2
- May 17, 2016
  - Substantial completion of all 8 engines

# Rule 1110.2 (d)(1)(H)(ii)



interval averaging time for the first 4 months of the retrofitted engine's operation and up to a 24 hour fixed interval averaging time thereafter. For purposes of determining compliance using a longer averaging time:

(i) An operator shall not average data during one-minute periods in which the underlying equipment is not operated or when the CEMS is undergoing zero or calibration checks, cylinder gas audits, or routine maintenance in accordance with the provisions in Rules 218 and 218.1.

(ii) Notwithstanding the requirements of Rules 218 and 218.1, for one-minute time periods where NOx and/or CO CEMS data are greater than 95 percent of the Rule 218.1 Full Scale Range while the underlying equipment is operating, an operator shall use substitute data. A concentration equivalent to 3 times the NOx and/or CO emission limits in Table III-B (each corrected to 15% O2) shall be used as substitute data.

# Thank You

**CONTACT:**

Orange County Sanitation District
Lisa Rothbart (714) 593-7405
Vlad Kogan (714) 593-7085

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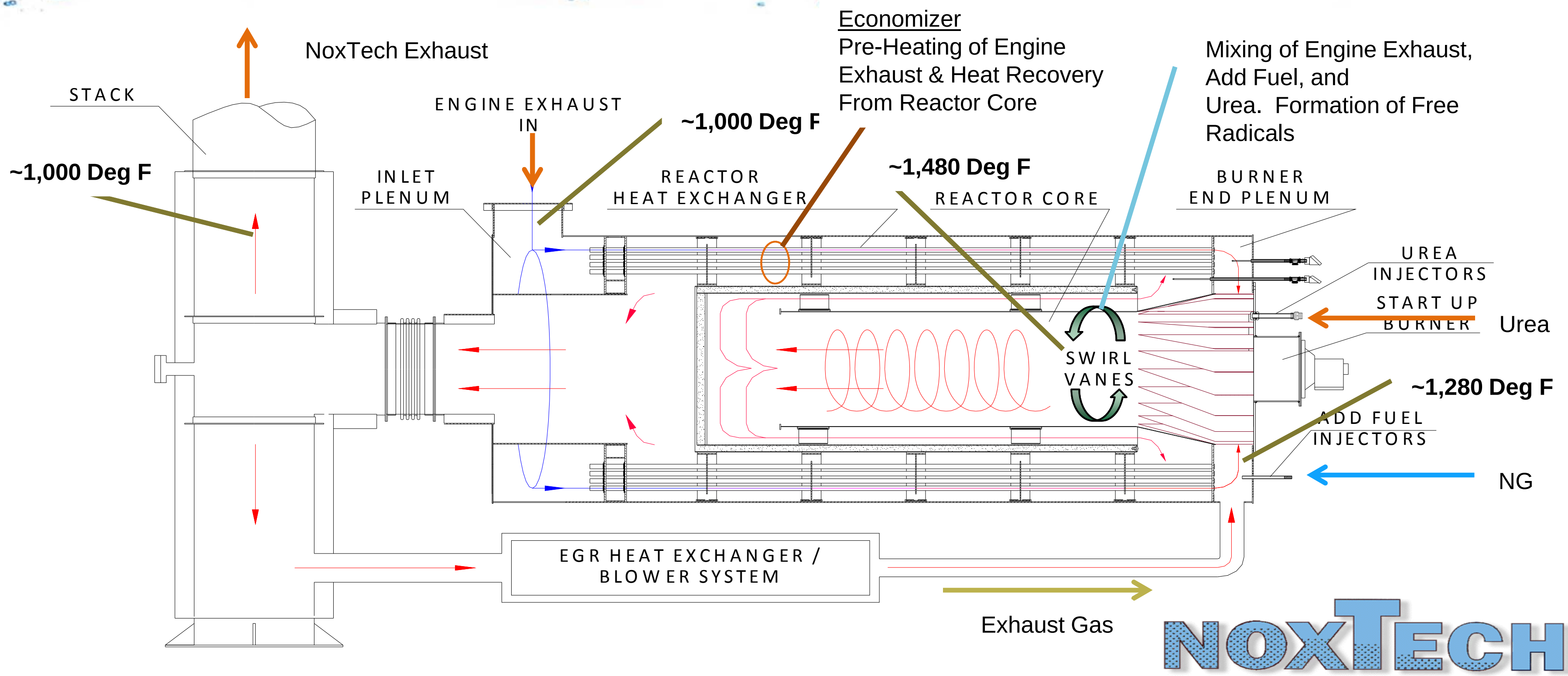
# TVRWRF NoxTech Project

**AQMD Biogas User Group Meeting**
**January 14, 2015**

**Mark E. Iverson, P.E.**
**Director of Maintenance**

# NoxTech at the TVRWRF

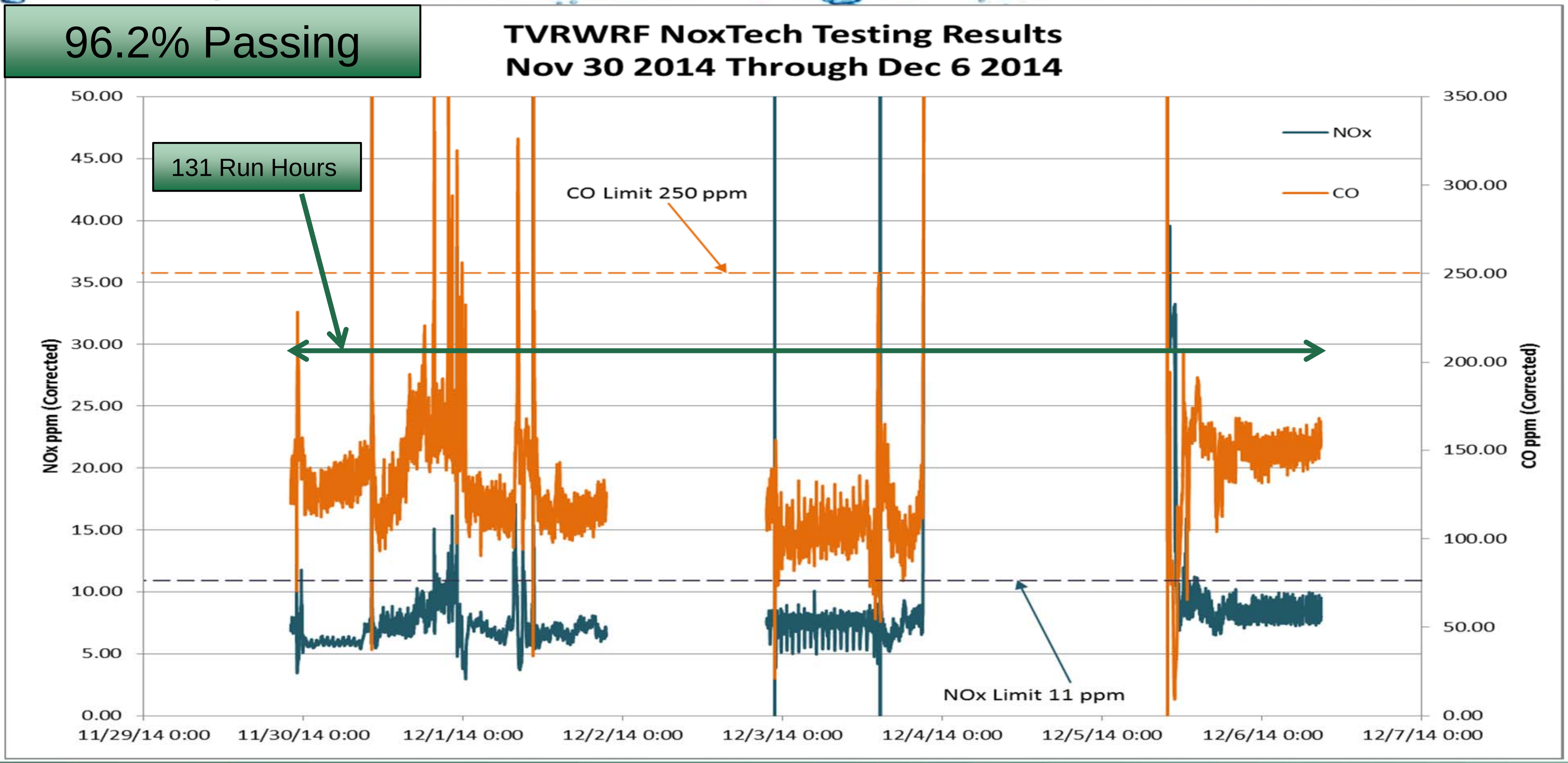
# NoxTech Process



# TVRWRF Start-Up Testing Summary

- Start-Up Testing: Sept 23 through Dec 6
- Total Run Hours: 425
- Overall: 78.9% Passing NOx and CO
- Last 131 Hours: 96.2% Pass NOx and CO

# TVRWRF Final Testing Results



# TVRWRF Key Findings

- System works well on biogas
- Number of engines has little effect on performance
- Engine fuel has little effect on performance
- NOx Analyzer key to system performance
- Existing Chemiluminescent NOx Analyzer difficult to maintain
- NOx analyzers needed both before and after NoxTech unit
- Automatic isolation valve with drip-tight seal needed for engine exhaust

# Next Steps

- Get additional funding approval
- Start six-month demonstration testing
- Design and install drip-tight exhaust isolation valves
- Evaluate solid-state NOx analyzers
- Install NOx analyzers before and after NoxTech Unit
- Complete installation of NoxTech unit at TVRWRF

EASTERN MUNICIPAL WATER DISTRICT

# Contact Information

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# Attachment F

## Memo to File (BACT No. 363)

clarification of SOx emission standards
&
removal of unnecessary SOx conversions

# Memo

SACRAMENTO METROPOLITAN AIR QUALITY MANAGEMENT DISTRICT

**To:** FILE [BACT No. 363]
**From:** Joanne Chan
**Date:** 07/10/2024
**Re:** Clarification of SOx BACT Standard and Removal of Unnecessary SOx Conversions

---

The proposed Best Available Control Technology (BACT) Determination No. 363 is a project-specific determination for Sacramento Area Sewer District's permit applications # 27782-27785 for Digester Gas-Fired, Prime Power Engines operating at a wastewater treatment facility.

The proposed BACT Determination No. 363, which was publicly noticed on 6/14/2024, contained some errors due to a calculation error in converting the SOx emission standards from ppm to g/hp-hr. Additionally, because the SOx standards apply to the sulfur content in the fuel (prior to combustion in the engine), the conversions of the ppm standards to g/hp-hr were unnecessary and, therefore, have been removed from the emission standard tables.

Please note that the actual SOx emission standards (in ppm) remain unchanged from the proposed BACT and the final BACT determination. The clarification of the SOx BACT standards and the removal of the unnecessary SOx conversions were made on the pages outlined in the table below:

| **BACT No. 363 section or page #** | **Proposed BACT No. 363** (publicly noticed on 6/14/2024) | **Final BACT No. 363** |
|---|---|---|
| Summary Page table – SOx Standard | 40 ppmvd daily average (0.52 g/hp-hr), or see comments below. | Sulfur content of fuel (calculated as $H_2S$): 40 ppmvd daily average, or see comments below. |
| Summary Page comments box | 40 ppmvd monthly average (0.52 g/hp-hr) and 500 ppmvd 15-minute average (6.45 g/hp-hr). | 40 ppmvd monthly average and 500 ppmvd 15-minute average. |
| SCAQMD section, SCAQMD BACT table footnote (B)<br>*staff report page 12* | Demonstrates compliance with SCAQMD Rule 431.1. | Demonstrates compliance with SCAQMD Rule 431.1 for sulfur content of fuel (calculated as $H_2S$) for sewage digester gas. |

| **BACT No. 363 section or page #** | **Proposed BACT No. 363** (publicly noticed on 6/14/2024) | **Final BACT No. 363** |
|---|---|---|
| Table Summarizing the Achieved in Practice Standards – SOx ranking #1<br><br>*staff report page 28* | 40 ppmvd daily average (0.52 g/hp-hr), or 40 ppmvd monthly average (0.52 g/hp-hr) <u>and</u> 500 ppmvd 15-minute average (6.45 g/hp-hr) | 40 ppmvd daily average, or<br>40 ppmvd monthly average<br><u>and</u> 500 ppmvd 15-minute average<br><br>For sulfur content of fuel (calculated as $H_2S$) for sewage digester gas. |
| Table Summarizing the Achieved in Practice Standards – SOx ranking #2<br><br>*staff report page 28* | 150 ppmvd total sulfur in biogas, or 1.93 g/hp-hr total sulfur in biogas | 150 ppmvd total sulfur in biogas |
| Best Control Technologies Achieved table – SOx Standard<br><br>*staff report page 30* | 40 ppmvd daily average (0.52 g/hp-hr), or 40 ppmvd monthly average (0.52 g/hp-hr) <u>and</u> 500 ppmvd 15-minute average (6.45 g/hp-hr) | Sulfur content of fuel (calculated as $H_2S$):<br>40 ppmvd daily average, or<br>40 ppmvd monthly average <u>and</u> 500 ppmvd 15-minute average |
| Selection of BACT<br><br>*staff report page 33* | 40 ppmvd daily average (0.52 g/hp-hr), or 40 ppmvd monthly average (0.52 g/hp-hr) <u>and</u> 500 ppmvd 15-minute average (6.45 g/hp-hr) | Sulfur content of fuel (calculated as $H_2S$):<br>40 ppmvd daily average, or<br>40 ppmvd monthly average <u>and</u> 500 ppmvd 15-minute average |
| Attachment D – Conversions | Description of the spreadsheet and what was changed.<br><br>• Deleted rows for $SO_2$ & $H_2S$ calculations.<br><br>• Updated comment box to reference SBAPCD guidance document's applicable formula sections. | Updates to the spreadsheet comment box:<br><br>Conversions for the emission standard verification (ppmv to g/bhp-hr) are calculated based on the Santa Barbara County APCD's Piston IC Engine Technical Reference Document (dated 11/01/2002), formula in Section II.B7. Pursuant to Section III.A1.(d), SOx emission factors should be based on mass emission calculations (such as the formula found in Section II.A5 - Fuel Sulfur Mass Balance for Gaseous Fuels). |

| BACT No. 363 section or page # | Proposed BACT No. 363 (publicly noticed on 6/14/2024) | Final BACT No. 363 |
|---|---|---|
| Attachment F – Memo | N/A | Memo provides clarification of the SOx emission standards & explains the removal of unnecessary SOx conversions. |

**APPROVED BY:** Brian F Krebs **DATE:** 7/16/2024