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SCAQMD PROTOCOL: Improvement of the Efficiency of a Natural Gas-Fired Boiler or Process Heater

I. Introduction

The purpose of this protocol is to establish a method to quantify voluntary reductions in greenhouse gas (GHG) emissions resulting from an improvement in the efficiency of a boiler or process heater (B/PH).

For practical purposes, the only GHG that is emitted in significant quantities from a B/PH is carbon dioxide (CO_2), so this protocol focuses on reductions in emissions of that gas. CO_2 emissions result from combustion of carbon in the fuel plus any CO_2 already contained in the fuel. Since CO_2 is the direct result of fuel combustion, any improvement in the efficiency of a B/PH will reduce fuel use and CO_2 emissions.

II. Definitions

For purposes of this protocol, the following definitions shall apply:

a) ADDITIONAL means that the greenhouse gas reductions achieved throughout the duration of the activity that generates certified greenhouse gas emission reductions are: a) not occurring due to routine equipment replacement; and b) are not otherwise required and would not occur as a result of any local, state, or federal regulation, or any legal instrument, to ensure no double counting of reductions unless authorized by the regulation or legal instrument. For the purpose of this protocol, a B/PH located at a facility under a GHG cap-and-trade program would not be eligible to generate certified GHG emission reductions.

b) A BOILER is any combustion equipment used to produce steam or to heat water.

c) COMBUSTION EFFICIENCY of a B/PH is 100 percent minus percent flue loss (percent flue loss is based on input fuel energy), on a higher heating value basis.[1]

d) HIGHER HEATING VALUE (HHV) of a fuel is the high or gross heat content of the fuel with the heat of vaporization included. The water vapor is assumed to be in a liquid state.

e) A PROCESS HEATER is any combustion equipment which transfers heat from combustion gases to a process stream. Process Heater does not include any kiln or oven used for drying, curing, baking, cooking, calcining, or vitrifying; or any unfired waste heat recovery heater that is used to recover sensible heat from the exhaust of any combustion equipment.

[1] This definition is used by federal (10CFR431.82) and state efficiency regulations.

f) NATURAL GAS is a mixture of gaseous hydrocarbons, with at least 80 percent methane (by volume), and of pipeline quality, such as the gas sold or distributed by any utility company regulated by the California Public Utilities Commission.

g) A STANDARD CUBIC FOOT (SCF) is that mass of a gas that occupies one cubic foot at standard conditions of temperature and pressure—60 ^{o}F and 29.92 In. mercury.

h) THERMAL EFFICIENCY of a B/PH is the fraction of the input fuel energy, on a higher heating value basis, that is recovered as heat content of the water or steam product or the process stream.

III. Eligibility

a) This protocol is for B/PHs fired on natural gas only.

b) This protocol may be used for the following types of efficiency improvements on a natural gas-fired B/PH:

   1) Addition of a combustion air preheater, economizer or other system that reduces the flue gas exhaust temperature and increases the B/PH thermal efficiency.

   2) Addition of a system that monitors, controls and reduces the excess combustion air, i.e., an oxygen trim system (OTS).

c) The first written contractual commitment for the efficiency improvement must have occurred on or after January 1, 2009.

d) The B/PH must be located in AQMD.

e) The efficiency improvement must be additional, as defined in Section II. Some examples of non-additional efficiency improvements are:

   1) If the B/PH or the upstream fuel used for the B/PH is included in a GHG cap-and-trade program, the GHG emission reductions will not be considered to be additional, and certified GHG emission reductions cannot be claimed.

   2) In the case of adding OTS, if the OTS is necessary for reduced NOx operation of the B/PH to meet the requirements of AQMD Rule 1146 or 1146.1, the GHG emission reduction does not qualify as additional.

   3) If the B/PH is subject to the California Appliance Efficiency Regulation [California Code of Regulations (CCR), Title 20, Division 2, Chapter 4, Article 4, Sections 1601-1608 or subsequent revisions], the minimum pre-improvement efficiency that may be used in calculating the GHG emission reduction must correspond to the minimum required by the regulations.

f) The equipment operator must notify the Executive Officer 30 days prior to commencing operation of the new or improved B/PH.

g) Projects that receive public grant money or rate payer rebates are not eligible for certified emission reductions under this protocol.

IV. Calculation Procedures for the GHG Emission Reduction and Other Emission Co-Benefits

a) Overall Approach

GHG emission reductions are determined after the end of each calendar year. No GHG emission reduction may be claimed for operation of the B/PH prior to the project initiation date. The project initiation date is the date on which the new or modified B/PH is placed into service.

The GHG emission reduction is the difference between the Modeled Baseline Emissions and the Project Emissions.

GHG reduction = Modeled Baseline Emissions (MBE) – Project Emissions (PE)

PE is the actual annual CO_2 emissions after the B/PH efficiency improvement has been implemented.

MBE are the emissions that would have occurred if the B/PH efficiency improvement measure had not been taken. MBE are calculated based on the PE, taking into account the B/PH thermal efficiency with and without the efficiency improvement.

To be consistent with the international convention for GHG emissions, PE and MBE are expressed in metric tons CO_2e per year.

If, during any portion of the year, the B/PH or the upstream fuel used for the B/PH was included in a GHG cap-and-trade program, the GHG emission reductions will no longer be considered to be additional, and certified GHG emission reductions can no longer be claimed. Co-benefits are to be calculated each year, but no credits will be issued for SIP approved rules. Co-benefits could be used for CEQA mitigation.

b) Project Emissions (PE)

Direct CO_2 emissions from natural gas combustion are calculated using the following equation[2].

$$PE = Fuel \times 1027 \frac{Btu}{scf} \times 53.02 \frac{kg\ CO_2}{MMBtu} \times 0.001 \frac{metric\ tons}{kg}$$

Where:

PE = metric tons of CO_2 emissions

Fuel = volume of natural gas combusted, millions of standard cubic feet (scf)

1027 = default higher heating value, Btu/SCF

53.02 = default carbon dioxide emission factor, kg CO_2 per MMBtu

0.001 = factor to convert kg to metric tons

[2] This equation is based on the procedure specified in CCR, Title 17, Subchapter 10, Article 2, Mandatory Greenhouse Gas Emissions Reporting (http://www.arb.ca.gov/regact/2007/ghg2007/frofinoal.pdf), Section 95125(a)(2).

c) Modeled Baseline Emissions (MBE)

The calculation procedure for the MBE will depend of the type of B/PH efficiency improvement.

1) Retrofit of an Economizer or Combustion Air Preheater

An economizer improves the efficiency of a B/PH by reducing the exhaust temperature and transferring recovered heat to B/PH feed water or other fluid. A combustion air preheater is similar, but transfers the heat to the combustion air. Sufficient space should be allowed between the B/PH exhaust outlet and the economizer or air preheater inlet to measure B/PH exhaust temperature before the economizer or air preheater so that the B/PH efficiency can be determined with and without the economizer or air preheater.

The MBE will be calculated as follows:

$$\text{MBE} = \text{PE} \times \frac{\text{(thermal efficiency with economizer/air preheater)}}{\text{(thermal efficiency without economizer/air preheater)}}$$

2) Retrofit of an Oxygen Trim System (OTS)

An OTS improves efficiency by reducing the exhaust temperature and exhaust flow rate, thereby reducing the amount of stack heat losses. To determine the GHG emissions benefit, the thermal efficiency before and after installation of the OTS must be established. To provide the information needed to determine the thermal efficiency before the OTS is installed, the flue gas O_2 and temperature must be measured at the B/PH outlet before installation of the OTS.

The MBE will be calculated as follows:

$$\text{MBE} = \text{PE} \times \frac{\text{(thermal efficiency with OTS)}}{\text{(thermal efficiency before OTS installation)}}$$

For a B/PH that is subject to the California Appliance Efficiency Regulation [California Code of Regulations (CCR), Title 20, Division 2, Chapter 4, Article 4, Sections 1601-1608 or subsequent revisions], if the pre-improvement combustion efficiency is less than the minimum required by the regulation, the pre-improvement thermal efficiency value used in the MBE calculation must be increased from the measured value by the amount by which the measured combustion efficiency is below the required minimum.

V. Project Monitoring

a) Overview

Project developers are responsible for monitoring the performance of the project and operating the improved B/PH in a manner consistent with the manufacturer's recommendations, measuring annual B/PH fuel use with a dedicated fuel meter, and calculating actual B/PH thermal efficiency based on flue gas measurements. The thermal efficiency monitoring requirements, based on the type of project, are summarized in the following table.

Project Type	**B/PH Thermal Efficiency Monitoring**
Retrofit of an Economizer or Combustion Air Preheater	Annual test of B/PH thermal efficiency with and without economizer or combustion air preheater for Section IV c) 1) calculation
Retrofit of an Oxygen Trim System (OTS)	• One-time test of B/PH thermal efficiency without OTS for Section IV c) 2) calculation • Annual test of B/PH thermal efficiency to determine B/PH thermal efficiency with OTS for Section IV c) 2) calculation

Procedures to be used to calculate the B/PH efficiency, perform the required O_2 and temperature measurements and measure the fuel usage are presented below.

b) B/PH Thermal Efficiency

1) Boiler Efficiency Calculator

The procedures in this section are for determining the thermal or combustion efficiency before and after an efficiency improvement that is achieved by retrofitting an economizer, air preheater, or OTS to an existing B/PH. The efficiency of the improved B/PH must be checked annually using these procedures.

The American Society of Mechanical Engineers has a Power Test Code for Fired Steam Generators (PTC 4 – 1998) that requires detailed measurements of all inputs and all outputs. The test method is the most accurate one, but is unnecessarily complicated for the purposes of this protocol.

The Natural Resources Canada Office of Energy Efficiency has developed a simple and free online Boiler Efficiency Calculator tool that can determine the thermal or combustion efficiency of a B/PH with measurements of only the flue gas temperature and oxygen content, and the combustion air temperature. It is available at http://www.oee.nrcan.gc.ca/industrial/technical-info/tools/boilers/index.cfm?attr=24.

The Boiler Efficiency Calculator is based on the ASME's Power Test Code for Steam Generating Units (PTC 4.1-1964, re-affirmed 1973, also ANSI PTC 4.1-

1974, reaffirmed 1985). This is an older code that was replaced by the newer PTC 4-1998.

The calculator uses a simplified version of the Indirect Method from the older PTC 4.1 for determining efficiency, which calculates thermal efficiency by determining the major energy losses. The losses include:

- stack losses due to the flue gas, that are calculated based on the measured temperature and oxygen content. This is the majority of all losses.
- an estimate of radiation and convection losses; and
- unaccounted losses. For natural gas fuel, the calculator user should enter 0.1% for this minor loss.

The calculator will also calculate the thermal efficiency with and without a non-condensing economizer or a combustion air preheater.

For a B/PH that is subject to the California Appliance Efficiency Regulations, combustion efficiency will be determined with the Boiler Efficiency Calculator, but with radiation, convection and unaccounted losses set to zero, as required by federal and state regulations.

2) Correction for Condensing Economizers

Since the calculator assumes a non-condensing economizer, a correction must be added if the economizer is a condensing economizer. For this case, the fraction of the flue gas moisture that will condense is calculated from the flue gas exit temperature, and the efficiency calculated by the calculator is increased to account for the sensible and latent heat of condensation recovered from the water that condenses on the economizer surface. The calculation procedure is as follows.

A. Calculate the partial pressure of water in the flue gas.

$$PP = 2.8082 - 0.1168 \times O_2$$

Where PP = partial pressure of water, psia

O_2 = flue gas oxygen content, vol. % (dry)

This equation is based on the natural gas composition that is assumed in the calculator.

B. Calculate the vapor pressure of water at the flue gas exit temperature

$$VP = 9 \times 10^{-7} \times FGT^{3.0136}$$

Where VP = vapor pressure of water, psia

FGT = flue gas temperature at the economizer exit, ^{o}F

This equation is based on the water vapor pressure table in the "Useful Tables" handbook published by the Babcock & Wilcox Co., Barberton, Ohio.

C. Calculate the fraction of the flue gas water content that will condense

$$F = 1 - VP/PP$$

Where F = fraction of flue gas water that will condense.

If F is not at least 0.1, the economizer is not a condensing economizer.

D. Calculate the sensible and latent heat (LH) of condensation that is recovered from the flue gas water that condenses.

$$EFF_{LH} = F \times .00935 \times (1087 + 0.467 \times FGT - CAT)$$

Where:

EFF_{LH} = heat reclaimed from condensed water as percent of fuel HHV, %

CAT = temperature of inlet combustion air to the B/PH, ^{o}F

This equation is based on the equation used in the calculator to calculate the heat loss associated with the flue gas moisture but is applied here only to the fraction of the flue gas water that condenses.

E. Calculate the corrected B/PH thermal efficiency.

$$EFF_{corr} = EFF_{calc} + EFF_{LH}$$

Where:

EFF_{corr} = thermal efficiency including reclaimed latent heat of condensation, %

EFF_{calc} = thermal efficiency with economizer, calculated using the calculator, %

c) Flue Gas/Combustion Air Measurements

1) Pre-Improvement Measurements

The determination of the thermal efficiency for an existing B/PH is sometimes required, as specified above, before an OTS is installed. The following requirements apply to the needed combustion air temperature, and flue gas exhaust temperature and oxygen content measurements:

- The measurements will be taken while the B/PH is operating within 5% of its most common in-service load (excluding low-fire standby operation). The operator must provide records, or other information if records do not exist, to substantiate the choice of this load.
- The measurements will be taken within 24 hours after the B/PH is tuned up in its normal manner. The operator must provide records to demonstrate that the B/PH has been tuned in the normal manner. (By purposely mistuning a B/PH, the thermal efficiency can reduced, which would cause an over calculation of the GHG emission reduction from the efficiency improvement method.)

- The flue gas oxygen content measurements will be conducted using the equipment, calibration procedures, and sampling procedures of AQMD's "Protocol for the Periodic Monitoring of Oxides of Nitrogen, Carbon Monoxide, and Oxygen from Units Subject to South Coast Air Quality Management District Rule 1146 and 1146.1" , except that:
    - The measurements will be taken at each of three points located along one cross-sectional axis of the stack at 16.7, 50 and 83.3 percent of the stack diameter and then averaged; and
    - The sampling time at each point will be a minimum of 5 minutes.
- The flue gas exhaust temperature will be measured simultaneously with the flue gas oxygen measurements at the same three points, and the combustion air temperature will be measured simultaneously at one point located within one foot of the combustion air intake, but as far away from any hot surfaces as possible.
- The flue gas and combustion air temperatures will be measured by instruments that have been calibrated in accordance with the AQMD Source Test Methods, Chapter III – Calibrations (http://www.aqmd.gov/tao/methods/stm/stmCh3_Calibrations.pdf)

2) Post-Improvement Measurements for an OTS Retrofit

Since pre-improvement measurements are required for a B/PH before it will have an OTS installed, the post-improvement measurements must be conducted in the same manner as the pre-improvement measurements, i.e. at the same load, and with the same measurement procedures, except for the following:

- For a B/PH rated at >2 MMBtu/hr, measurements must be conducted at the same time and each time that the periodic emission checks are done, as required by paragraph (d)(8) of AQMD Rule 1146 for B/PH rated at 5 MMBtu/hour or more, or paragraph (d)(7) of AQMD Rule 1146.1 for B/PH rated at less than 5 MMBtu/hour and more than 2 MMBtu/hour.
- As required by paragraph (d)(2) of Rules 1146 and 1146.1, measurements must be conducted at least every 250 operating hours or at least 30 days after any tuning or servicing of a B/PH, unless it was an unscheduled repair.
- At least one measurement must be conducted in each calendar year.
- The thermal efficiency or combustion efficiency is calculated, as previously described using the Boiler Efficiency Calculator, each time measurements are made. The efficiency for a calendar year is the average of all the efficiency measurements in that calendar year.

3) Post-Improvement Measurements after Retrofit of a Combustion Air Preheater or Economizer

The post-improvement measurements following retrofit of an combustion air preheater or economizer are conducted in the same manner as described in the previous paragraph, except that:

- Because pre-improvement measurements were not required, the measurements must be taken while the B/PH is operating at its current most common in-service load ± 5%. The operator must provide records, or other information if records do not exist, to substantiate the choice of this load.
- Measurements of flue gas temperature and oxygen content must be taken simultaneously both upstream and downstream of the air preheater or economizer.
- The thermal efficiency without the economizer/air preheater is calculated using the measurements upstream of the economizer/air preheater.
- The thermal efficiency with the economizer/air preheater is calculated using the measurements downstream of the economizer/air preheater.

d) Determination of Fuel Usage

Any B/PH for which a GHG emission reduction is to be certified must have a dedicated fuel meter. The only exception is if the GHG emission reduction involves more than one B/PH and all involved units are identical, have the same average operating loads, and receive identical improvements. In that case, a common fuel meter may be shared by all involved units.

The fuel meter must have an accuracy of ±5% or better, as specified by the manufacturer, and must be maintained and calibrated in a manner and at a frequency required to maintain this level of accuracy.

If the fuel meter fails a calibration test (tested to be outside of allowable 5% margin of error), the fuel usage shall be assumed to be zero until the meter passes a subsequent calibration test. In the event that the fuel meter is inoperable, fuel usage shall be assumed to be zero during the period of inoperability.

The fuel meter must be installed, maintained and operated in a manner consistent with the manufacturer’s recommendations; and must be tamper proof and, if a totalizer type, non-resettable. The seals installed by the manufacturer must be intact to prove the integrity of the measuring device. If the meter is unsealed for maintenance or repairs, it must be resealed by an authorized manufacturer’s representative.

VI. Project Plan

The project developer must complete and submit for the approval of the Executive Officer a Project Plan that includes: the information required by Rule 2701(c)(3), the fees required by Rule 306 and the Project Submittal Form in Appendix B prior to commencing the GHG reduction. All information in the plan, unless marked confidential, may be made publicly available.

VII. Project Recordkeeping and Reporting

a) Recordkeeping

For purposes of independent verification and historical documentation, project developers shall keep all information required by this protocol for a period of five years after the last calendar year for which a GHG emission reduction is claimed. Records shall include descriptions of all project equipment and methods and all data inputs and calculations for the calculation of the baseline emissions and project emission reductions. Records shall include, but not be limited to, the following data and information.

- B/PH make, model, serial number, rated input (Btu/hr, higher heating value), rated steam production (lb/hr) and conditions (psig and ^oF) or rated fluid throughput and inlet/outlet temperatures (^oF), design heat transfer to steam or fluid at rated input (Btu/hr), design thermal efficiency (%) based on 60 ^oF inlet air and feedwater temperature, and design flue gas exit temperature and O_2 content (vol. %, dry).
- Make, model, serial number of economizer, combustion air preheater or OTS and SCAQMD permit application or permit number.
- Evidence of startup of the improved B/PH by the manufacturer or engineering firm, including the startup date.
- Fuel meter make, model, serial number.
- Method used to measure flue gas and combustion air temperatures.
- O_2 analyzer make, model, serial number.
- Fuel meter and O_2 analyzer calibration methods and results.
- QA/QC procedures and data.
- Fuel meter data that documents annual fuel usage.
- Flue gas O_2, flue gas temperature and combustion air temperature data.
- B/PH efficiency determinations using the Boiler Efficiency Calculator: computer screen-prints showing input data and results.
- Annual calculations: PE, MBE, GHG emission reductions and any co-benefits realized. [See Section VIII(a)].

b) Reporting

Project developers must annually report to AQMD, within 60 days of the end of each calendar year, the GHG emission reductions associated with a B/PH efficiency improvement that occurred the preceding year. Each annual report shall contain all data and calculations required to compute the GHG emission reduction for the year. Data and calculations to be included in the annual report shall include, but not be limited to, the following:

- Fuel meter make, model, serial number.
- Method used to measure flue gas and combustion air temperatures.
- O_2 analyzer make, model, serial number.
- Fuel meter and O_2 analyzer calibration methods and results.
- QA/QC procedures and data.
- Fuel meter data that documents annual fuel use.
- Flue gas O_2, flue gas temperature and combustion air temperature data.
- B/PH efficiency determinations using the Boiler Efficiency Calculator: computer screen-prints showing input data and results.
- Calculations: PE, MBE, GHG emission reduction and any other emission co-benefits. [See Section VIII(a)]

VIII. Appendices

a) Co-Benefits

Co-benefits are reductions of criteria pollutant emissions that are achieved because of the GHG-reduction project. B/PH co-benefits may include emission reductions of oxides of nitrogen (NOx), carbon monoxide (CO), volatile organic compounds (VOC) and particulate matter (PM). The co-benefits are calculated from the B/PH emission rates expressed as lb/MMBtu.

For NOx, the B/PH emission rate is based on the B/PH permit limit or AQMD rule limit, whichever is lower. If the NOx limit is expressed as ppmvd (volumetric parts per million on a dry basis) corrected to 3% O_2, it may be converted to lb/MMBtu using the following formula based on USEPA Method 19:

$$\text{Lb/MMBtu NOx} = \text{ppmvd @ 3\% } O_2 * .00121,$$

For CO, the emission rate is based on the permit limit if it is 100 ppmvd or less (corrected to 3% O_2). Otherwise the emission rate is based on the default emission factor used in AQMD's Annual Emission Report (AER) program, 84 lb/MMSCF fuel. If a permit limit is used, the conversion to lb/MMBtu is as follows (again based on USEPA Method 19):

$$\text{Lb/MMBtu CO} = \text{ppmvd @ 3\% } O_2 * .000737$$

If the 84 lb/MMSCF factor is used, the equivalent lb/MMBtu is .0818 based on 1027 Btu/SCF fuel HHV.

For VOC and PM, since there are typically no permit limits, the following emission rates, which are based on AQMD AER default factors and 1027 Btu/SCF fuel HHV, are used:

$$\text{Lb/MMBtu VOC} = 5.5 \text{ lb/MMSCF} /1027 = .00536$$

$$\text{Lb/MMBtu PM} = 7.6 \text{ lb/MMSCF} /1027 = .00740$$

For each pollutant, the emission reduction is calculated from the GHG emission reduction using the lb/MMBtu emission rate:

$$\text{Emission Reduction (tpy)} = \frac{\text{(MBE – PE) x Pollutant lb/MMBtu}}{\text{(53.02 kg/MMBtu) x 2}}$$

b) Project Submittal Form

The following form is to be used for reporting general project information to the AQMD in order to initiate the project listing process. All fields must be completed as thoroughly as possible. If a field is not applicable, insert N/A in the space provided. If the project is still in the planning/development phase, all fields must be completed using best available data and estimations.