San Joaquin Valley
Unified Air Pollution Control District

Best Performance Standard (BPS) x.x.xx

Date: 6/24/10

Class	**Steam Generators**
Category	**Oilfield**
Best Performance Standard	**Very High Efficiency Steam Generator Design With:** 1. A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by manufacturer) or a manufacturer's overall thermal efficiency rating of 88%. **And** 2. Variable frequency drive high efficiency electrical motors driving the blower and water pump.
Percentage Achieved GHG Emission Reduction Relative to Baseline Emissions	13.0%

District Project Number	C-1100391
Evaluating Engineer	Steve Roeder
Lead Engineer	Arnaud Marjollet
Initial Public Notice Date	April 28, 2010
Final Public Notice Date	May 28, 2010
Determination Effective Date	June 24, 2010

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I. Best Performance Standard (BPS) Determination Introduction

A. Purpose

To assist permit applicants, project proponents, and interested parties in assessing and reducing the impacts of project specific greenhouse gas emissions (GHG) on global climate change from stationary source projects, the San Joaquin Valley Air Pollution Control District (District) has adopted the policy*: District Policy – Addressing GHG Emission Impacts for Stationary Source Projects Under CEQA When Serving as the Lead Agency.* This policy applies to projects for which the District has discretionary approval authority over the project and the District serves as the lead agency for CEQA purposes. Nonetheless, land use agencies can refer to it as guidance for projects that include stationary sources of emissions. The policy relies on the use of performance based standards, otherwise known as Best Performance Standards (BPS) to assess significance of project specific greenhouse gas emissions on global climate change during the environmental review process, as required by CEQA. Use of BPS is a method of streamlining the CEQA process of determining significance and is not a required emission reduction measure. Projects implementing BPS would be determined to have a less than cumulatively significant impact. Otherwise, demonstration of a 29 percent reduction in GHG emissions, from business-as-usual, is required to determine that a project would have a less than cumulatively significant impact.

B. Definitions

Best Performance Standard for Stationary Source Projects for a specific Class and Category is the most effective, District approved, Achieved-in-Practice means of reducing or limiting GHG emissions from a GHG emissions source, that is also economically feasible per the definition of Achieved-in-Practice. BPS includes equipment type, equipment design, and operational and maintenance practices for the identified service, operation, or emissions unit class and category.

Business-as-Usual is - the emissions for a type of equipment or operation within an identified class and category projected for the year 2020, assuming no change in GHG emissions per unit of activity as established for the baseline period, 2002-2004. To relate BAU to an emissions generating activity, the District proposes to establish emission factors per unit of activity, for each class and category, using the 2002-2004 baseline period as the reference.

Category is - a District approved subdivision within a “class” as identified by unique operational or technical aspects.

Class is - the broadest District approved division of stationary GHG sources based on fundamental type of equipment or industrial classification of the source operation.

C. Determining Project Significance Using BPS

Use of BPS is a method of determining significance of project specific GHG emission impacts using established specifications. BPS is not a required mitigation of project related impacts. Use of BPS would streamline the significance determination process by pre-quantifying the emission reductions that would be achieved by a specific GHG emission reduction measure and pre-approving the use of such a measure to reduce project-related GHG emissions.

GHG emissions can be directly emitted from stationary sources of air pollution requiring operating permits from the District, or they may be emitted indirectly, as a result of increased electrical power usage, for instance. For traditional stationary source projects, BPS includes equipment type, equipment design, and operational and maintenance practices for the identified service, operation, or emissions unit class and category.

II. Summary of BPS Determination Phases

The District has established oilfield steam generators as a separate class and category which requires implementation of a Best Performance Standard (BPS) pursuant to the District's Climate Change Action Plan (CCAP). The District's determination of the BPS for this class and category has been made using the BPS development process established in the District's Final Staff Report, *Addressing Greenhouse Gas Emissions under the California Environmental Quality Act.* A summary of the specific implementation of the phased BPS development process for this specific determination is as follows:

Table 1
BPS Development Process Phases for Oilfield Steam Generators

Phase	Description	Date	Description
1	Public Notice of Intent	2/9/10	The District's intent notice is attached in Appendix 1
2	BPS Development	2/25/10	The District's Public Participation request for information is attached in Appendix 3
3	Public Participation	4/28/0	A Draft BPS evaluation was provided for public comment. The District's notification is attached in Appendix 5
4	Public Comments	5/30/10	All public comments received and the District's responses are attached in Appendix 6
5	Finalization	6/22/10	The BPS established in this evaluation document is effective on the date of finalization.

III. Class and Category

In heavy oil production, steam generators are used to produce large quantities of steam. The steam is injected under great pressure into an oil production zone. The steam heats the crude oil, reducing its viscosity, making the oil easier to pump. The oil is pumped from the ground (as a produced fluid) and the oil contains a relatively large amount of water and dissolved gasses.

The water is separated from the oil in several stages, purified on-site, and used as feedwater for the steam generators.

Oilfield steam generators differ from typical boilers in several areas.

A. Steam generators produce large amounts of lower quality steam (in the area of 70%) under relatively high pressures (in the area of 1,000 psig).
B. The required temperature and pressure of the steam requirement varies depending upon the geological configuration of the wells that are being steamed.

C. Since the steam generator feedwater is generally water that has been produced from the oil wells, the temperature of the feedwater is relatively warm (above 115 degrees F), which limits overall thermal efficiency of the steam generator.
D. Steam generators typically operate constantly, year round, without stopping.
E. The useful output of the steam generated cannot be correlated to the useful product of *barrels of oil produced*, because the amount of steam and it's impact on each oil well is difficult to determine on an individual basis, and varies considerably due to the geological characteristics of each oil deposit and each well. Therefore, the useful output of a steam generator must be described in terms of steam generator heat output (in MMBtu/hour) per unit of steam generator heat input (MMBtu/hour), (which is thermal efficiency).

Therefore, oilfield steam generators have been designated as a separate class and category of boiler.

IV. Public Notice of Intent

Prior to developing the development of BPS for this class and category, the District published a Notice of Intent. Public notification of the District's intent to develop BPS for this class and category was sent on February 9, 2010 to individuals registered with the CCAP list server. The District's notification is attached in Appendix 1.

Comments received during the initial public outreach are presented in Appendix 2. These comments have been used in the development of this BPS as presented below.

V. BPS Development

STEP 1. Establish Baseline Emissions Factor for Oilfield Steam Generators

The Baseline Emission Factor (BEF) is defined as the three-year average (2002-2004) of GHG emissions for a particular class and category of equipment in the San Joaquin Valley (SJV), expressed as annual GHG emissions per unit of activity. The Baseline Emission Factor is calculated by first defining an operation which is representative of the average population of units of this type in the SJV during the Baseline Period and then determining the specific emissions per unit throughput for the representative unit.

A. Representative Baseline Operation

For oilfield steam generators, the representative baseline operation has been determined to be a 77% thermally efficient steam generator with a vertical convection section, and standard (non variable frequency drive) electric drive motors for the blower and water pump. This determination is based on a survey of permitted steam generators and submissions from the oilfield industry.

For the purpose of this document, thermal efficiency is defined as the ratio of the amount of heat transferred to the steam (useful heat output) compared to the amount of heat released during the combustion of the fuel (total heat input).

The following analysis of baseline steam generator GHG emissions is based on actual physical measurements taken from baseline-era steam generator S-1114-16. This steam generator is considered to be a typical industry-wide example of baseline steam generator operation.

B. Basis and Assumptions

- All direct GHG emissions are the result of the combustion of natural gas in the steam generator.
- Maximum heat input rating of the steam generator is 62.4 MMBtu/hr
- Actual fuel consumption of the steam generator 56.4 MMBtu/hr
- Thermal efficiency is 77.0% (heat output ÷ heat input)
- Heat output is (56.4 MMBtu/hr x 77%) = 43.4 MMBtu/hr
- The GHG emission factor for natural gas combustion is 117 lb-CO_2e/MMBtu (per CCAR document)[1]
- Thermal efficiency calculations are based on Higher Heating Value (HHV) of the natural gas
- Fuel measurements are based on a "gross dry basis", consistent with utility recording protocol
- Indirect emissions are produced due to operation of the electric water pump and air blower motors
- Blower motor hp at 60 hertz is 130 hp
- Blower motor electrical efficiency is 94.5%
- Water Pump motor input energy hp is 78.2 hp
- Water Pump motor output energy hp is 73.5 hp
- Indirect emissions from electric power consumption are calculated based on the current PG&E electric power generation factor of 0.524 lb-CO_2e per kWh (http://www.pge.com/about/environment/calculator/assumptions.shtml)
- Steam quality = 70%
- Steam temperature = 540 F
- Mass flowrate = 1,162,144 lb·water/day
- Stack temperature = 328 F
- Feedwater temperature = 132 F
- Convection section surface area = 7,590 square feet

[1]EF CO_2e = 52.92 kg/MMBtu x 2.2046 kg/lb = 116.67 →117 lb·CO_2e/MMBtu

C. Unit of Activity

To relate Business-as-Usual to an emissions generating activity, it is necessary to establish an emission factor per unit of activity, for the established class and category, using the 2002-2004 baseline period as the reference. The resulting emission factor is a combination of direct emissions from fuel consumption and indirect emissions from electricity consumption.

The useful output of the steam generated cannot be correlated to *barrels of oil produced*, because the amount of steam and it's impact on each oil well is difficult to determine on an individual basis, and varies considerably due to the geological characteristics of each oil deposit and each well. Therefore, the useful output of a steam generator must be described in terms of steam generator heat output (in MMBtu/hour) per unit of steam generator heat input (MMBtu/hour), which is thermal efficiency.

D. Calculations

1. Indirect GHG Emissions from blower motor

130 hp x 0.746 kW/hp x (1/94.5%) x 0.524 lb·CO_2e/kW·hr = 53.8 lb·CO_2e/hr
53.8 lb·CO_2e/hr ÷ 43.4 MMBtu = 1.24 lb·CO_2e/MMBtu (of heat output)

2. Indirect GHG emissions from the water pump

78.2 hp x 0.746 kW/hp x 0.524 lb·CO_2e/kW·hr = 30.6 lb·CO_2e/hr
30.6 lb·CO_2e/hr ÷ 43.4 MMBtu/hr = 0.705 lb·CO_2e/MMBtu (of heat output)

3. Direct GHG Emissions

56.4 MMBtu/hr (input) x 117 lb·CO_2e/MMBtu = 6,599 lb·CO_2e/hr
6,599 lb·CO_2e/hr ÷ 43.4 MMBtu/hr = 152 lb·CO_2e/MMBtu (of heat output)

4. Total Baseline Emissions (Indirect + Direct emissions)

BE = (1.24 + 0.705 + 152) lb·CO_2e/MMBtu = 153.945 lb·CO_2e/MMBtu
BE = 153.945 lb·CO_2e/MMBtu ÷ 2,205 lb/metric ton
= 0.069816 metric ton·CO_2e/MMBtu (heat output)

BEF = 0.069816 metric tons·CO_2e/MMBtu (of heat output)

STEP 2. List Technologically Feasible GHG Emission Control Measures

For oilfield steam generators, all technologically feasible GHG emissions reduction measures are listed, including equipment selection, design elements and best management practices that do not result in an increase in criteria pollutant emissions compared to the proposed equipment or operation.

Based on a review of available technology and with consideration of input from industry, manufacturers, and other members of the public, the following is determined to be the *technologically feasible* GHG emission reduction measures for oilfield steam generators. Please note that while these measures are technologically feasible, further analysis will follow which will conclude whether the listed technologically feasible measures can be considered candidates for the BPS.

Table 2
Technologically Feasible GHG Control Measures for Oilfield Steam Generators

Control Measure	Qualifications
1. High efficiency steam generator design	A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) or a manufacturer's overall thermal efficiency rating of 88%.
2. Additional economizer	Additional vertical heat exchange to further preheat water with exhaust gasses
3. Limiting the FGR controls	Reducing the recirculated flue gas air can reduce the amount of wasted heat which leads to thermal inefficiency
4. Ammonia Injection to Control NO_x	This would allow for even less recirculated flue gas and further improve the thermal efficiency
5. Variable frequency drive high efficiency electrical motors driving the blower and water pump	Ability to run the water pump no faster than it needs to be run, and ability to vary airflow through the steam generator without the need to use restrictive louvers
6. Very High efficiency steam generator design	1. A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) **or** a manufacturer's overall thermal efficiency rating of 88%. **And** 2. Variable frequency drive high efficiency electrical motors driving the blower and water pump

Discussion of Each Technologically Feasible Item

1. High efficiency steam generator design using a high efficiency convection section to achieve at least 88% thermal efficiency

Prior to the baseline period, hundreds of oilfield steam generators existed. Many oilfield steam generators burned crude oil to produce steam. One design criteria was that the stack temperature needed to remain relatively high to avoid the SO_x from condensing in the stack. This would corrode the convection section and give rise to visible emissions. The minimal convection section (heat transfer section) was of the vertical or pyramid style, and known to be only efficient enough to support the goal of maintaining a high exhaust temperature. Economically, these units were built on a small foot print, and a vertical heat transfer section seemed like a reasonable design for the efficiency required at the time.

During the phase-out of crude oil and high-sulfur gaseous fuels, the use of sulfur scrubbers was required along with the use of other equipment that would lower SO_x emissions to District standards. At the same time, low-NO_x emissions were promulgated by the District.

In many cases, existing steam generators, many of them of the crude oil-fire design, were simply retrofit with low-NO_x burners and FGR to meet the lower NO_x standards. While these retrofitted units proved to meet the NO_x objective, they were not particularly thermally efficient. At the time, it was more cost-effective (up front) to retrofit an old steam generator with new burners than to erect a whole new modern steam generator, and as such, the typical “retrofit” steam generator made up the bulk of baseline-era steam generators.

With the District’s lower sulfur emissions standards, the combusted sulfur is less likely to condense in the stack and thus stack temperatures could be lowered considerably, by extracting more heat out of the exhaust stream. This allowed steam generator designers to get more overall thermal efficiency out of steam generators.

One key feature of this re-design for modern-era steam generators was the *horizontal convection section*. On a modern-era steam generator (not a retrofit), the heat transfer section is laid down on the ground (on a long slab), since there is no shortage of space at oilfields. This allows for a massive increase in convection section heat transfer surface area, which is where most of the actual heat transfer takes place between the burning fuel and the steam. While a vertical or pyramid convection section could have a convection surface area of 7,590 square feet, a new larger horizontal convection section could be designed to easily accommodate a much larger convection section with a convective heat exchange surface area of over 20,000 square feet. The increased heat transfer takes advantage of the lower limit of the stack temperature (lowering the stack temperature by about 100 deg F, to approximately 229 deg F), and reclaims a lot of otherwise wasted heat for steam production. This increases the overall thermal efficiency of the steam generator. The result is that less fuel is required, and therefore fewer GHG emissions are released to produce the same quantity of steam.

As clarified in the “BPS Emission Factor” below, an achieved-in-practice steam generator with a properly sized convection section allows for an overall thermal efficiency of at least 88%, which corresponds to a *decrease in GHG emissions of 12.47% from baseline.*

The horizontal convection section with more heat transfer surface area has been achieved-in-practice, and will be a candidate for the oilfield steam generator BPS.

In order to specify the BPS, one important question must be answered.

> How much convection section heat transfer surface area is required to produce the established required thermal efficiency of steam generators of different heat input ratings?

Heat transfer in steam generators is based on the formula Q = U·S·DT, where
- Q = heat transfer (in MMBtu/hour),
- U = overall heat transfer coefficient,
- S = surface area, and
- DT = log of mean temperature difference

From the governing formula, it is clear that the relationship between the Q and S is linear, and intuitively it is clear that S limits Q. The higher the S for a given load, the more Q may be transferred to the steam.

The preponderance of oilfield examples indicate that the modern high efficiency convection section for an 85 MMBtu/hr steam generator, operating at 88% thermal efficiency, has a ratio (R) of 20,000 square feet of convection section surface area per 85 MMBtu/hour of maximum rated heat input.

To accommodate other heat input ratings, and allowing S to vary linearly with Q, the ratio necessary to produce the target 88% thermal efficiency is:

$$R = \frac{20{,}000\ ft^2}{85\frac{MMBtu}{hour}} = 235\frac{ft^2}{\frac{MMBtu}{hr}}$$

This ratio will be part of the equipment option in the BPS.

To complete the analysis, two other assumptions are discussed.

A. The surface area given is total heat transfer surface area in the convection section which includes the surface area of all of the fins
B. All steam generator tubes are made of a similar metallic composition

While the heat transfer capacity of one linear foot of bare tube is lower than the heat transfer capacity of one linear foot of an otherwise similar "finned" tube, the heat transfer capacity of 1 square unit of surface area of bare-tube is higher than the heat transfer capacity of 1 square unit of surface area of "fin", because the fin itself adds resistance to heat transfer. 235 square feet of bare tube surface area will have a higher thermal transfer capacity than 235 square feet of “fin” surface area.

There are many variations in fin design. Fins can be extruded, embedded, L-based, helically cut, etc., made of different materials, and some fins have serrations cut into them to increase turbulence and enhance heat transfer. While It is clear that fin design is paramount to heat transfer, the thermodynamics of individual fin designs are beyond the scope of this document. For the purposes of BPS, all fins will be considered to have the same heat transfer capacity per unit of surface area, so that the actual fin design will not be a necessary part of the BPS.

It is also important to note that the steam generator example described in detail that is capable of 88% thermal efficiency utilizes fins. It follows that otherwise similar steam generators that have the same surface area of bare tubes (without fins) will have a slightly higher heat transfer capacity. For simplicity and being conservative, the BPS standard will require 235 of heat exchange surface area in the convection section, and the type of fin or bare tube design will not be specified.

Historically, the more efficient steam generators with large convection section designs included a horizontal convection section. However, since the key design factor regarding overall thermal efficiency is the convection section’s heat exchanger surface area, it will not be necessary that the convection section be horizontal. While it is expected that almost every oilfield steam generator convection section design that meets the BPS will be horizontal, a “horizontal” or “lay down” convection section will not be mandatory, provided the convection section’s surface area specification is met.

Finally, since the metallic composition of the steam generator tubes are all designed for the same basic working environment, their synthesis (corrosion resistant steel) should remain somewhat consistent between various steam generators. For this reason, a detailed thermodynamic analysis of the heat transfer capacity of the tubes themselves isn't necessary, and will not be a consideration of the BPS analysis.

Since the efficiency of 88% was achieved through the use of a specific amount of convection section heat exchanger surface area, this option will be restated as follows:

> A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) **or** a manufacturer's overall thermal efficiency rating of 88%

2. Additional Economizer

Additional waste-heat can be transferred from the exhaust gasses to the steam by installing an extra economizer, further increasing the thermal efficiency of the steam generator.

Economizers are useful in steam generators that produce a higher quality and lower volume steam. With purified, de-ionized highly filtered water, high quality steam is possible and often necessary to serve a particular industrial need.

However, oilfield steam generators generally produce high volumes of lower quality steam from relatively dirty feedwater, and additional economizers are not currently employed.

In order to be considered BPS, the technology must be actually achieved-in-practice. Since new oilfield steam generators do not have added vertical economizers this technology is not achieved-in-practice in the oilfield, and therefore is precluded from being a candidate for BPS.

3. and 4. Limiting the FGR Controls and the Use of Ammonia Injection

Flue gas recirculation mixes a portion of the exhaust gas with the oxygen-rich incoming air in the burner's combustion zone. The added exhaust gas absorbs heat from the combustion process, lowering the peak combustion temperature below the threshold where excessive NO_x is formed. Proven FGR technology has been used in steam generators for years to meet the District's standards for low NO_x emissions. While FGR clearly lowers NO_x levels, additional fuel is required to produce the same amount of steam, which reduces the overall thermal efficiency of the unit and creates more GHG emissions per unit of steam output. Therefore, limiting the FGR rate might be a means of reducing GHG emissions.

The achievement of criteria emission standards (NO_x levels) is mandatory. The District realizes that while reducing the FGR rate on a steam generator will decrease GHG emissions, it will also increase NO_x emissions. This increase in NO_x emissions would have to be some how mitigated in order to maintain compliance with applicable NO_x emissions limits.

A common method of reducing NO_x emissions in many combustion devices, which could make a reduction in the FGR rate feasible, would be to supplement the FGR technology with a Selective Catalytic Reduction (SCR) system. With SCR, ammonia or urea is injected into the exhaust stack where the ammonia reacts in the presence of a catalyst with NO_x to produce elemental Nitrogen and water. The SCR reduces NO_x emissions without the need for such extensive FGR. However it should be noted that the SCR system itself results in higher exhaust stack resistance, the presence of which offsets some of the energy efficiency gains attributed to the reduced FGR requirement.

While promising, in order to be a BPS, this technology would have to be achieved-in-practice. To date, no oilfield steam generators are equipped with ammonia injection. Therefore, this technology can not be considered achieved-in-practice, and thus precluded from being a candidate for oilfield steam generator BPS.

5. Variable frequency drive high efficiency electrical motors driving the blower and water pump

According to the analysis that follows, the electric motors that drive the blowers and water pumps associated with oilfield steam generators contribute to indirect GHG emissions. High efficiency electric motors coupled with high efficiency variable frequency drives result in electricity savings. This reduces the indirect GHG emissions for the steam generator.

This electrical technology can save nearly 150,000 kW·hr/year on a typical oilfield steam generator. At an indirect emission factor of 0.524 lb·CO_2e/kW·hr, this amounts to a savings of 78,600 lb·CO_2e per year.

While this technology may result in only a 0.49% decrease in overall CO_2e as compared to the entire steam generator project, it does reduce GHG and it is achieved-in-practice. Therefore, this technology is a candidate for oilfield steam generator BPS for indirect GHG emissions.

6. Very high efficiency steam generator design using a high efficiency convection section to achieve at least 88% thermal efficiency

This option would consist on a combination of measure 1, *High efficiency steam generator design using a high efficiency convection section to achieve at least 88% thermal efficiency*, and measure 5, *Variable frequency drive high efficiency electrical motors driving the blower and water pump.*

These two options combined together represent the newest most efficient steam generator achieved-in-practice today, and both of these control measures put together represent the Best Performance Standard available.

STEP 3. Identify all Achieved-in-Practice GHG Emission Control Measures

Achieved-in-Practice is defined as any equipment, technology, practice or operation available in the United States that has been installed and operated or used at a commercial or stationary source site for a reasonable period of time sufficient to demonstrate that the equipment, the technology, the practice or the operation is reliable when operated in a manner that is typical for the process. In determining whether equipment, technology, practice or operation is Achieved-in-Practice, the District will consider the extent to which grants, incentives or other financial subsidies influence the economic feasibility of its use.

Pursuant to the discussion above for each technologically feasible item listed, those technologies that are achieved-in-practice have been identified as such and will be brought forward as achieved-in-practice GHG control measures, as indicated in the following table.

Table 3
Achieved-in-Practice GHG Control Measures for Oilfield Steam Generators

Control Measure	Achieved-Qualifications
1. High thermal efficiency steam generator	A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) **or** a manufacturer's overall thermal efficiency rating of 88%.
5. Variable frequency drive high efficiency electrical blower and water pump motors	95% NEMA efficiency
6. Very high thermal efficiency steam generator	1. A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) **or** a manufacturer's overall thermal efficiency rating of 88% **And** 2. Variable frequency drive high efficiency electrical motors driving the blower and water pump.

STEP 4. Quantify the Potential GHG Emission and Percent Reduction for Each Identified Achieved-in-Practice GHG Emission Control Measure

For each achieved-in-practice GHG emission, the following are identified:

a. Quantify the potential GHG emissions per unit of activity (G_a)
b. Express the potential GHG emission reduction as a percent (G_p) of Baseline GHG emissions factor per unit of activity (BEF)

This section will analyze a high thermal efficiency steam generator (88% thermal efficiency) that has a convection section with 20,000 square feet of heat transfer surface area, and variable frequency drive high efficiency electrical blower and water pump motors.

The following analysis of BPS steam generator GHG emissions is based on actual physical measurements taken from modern-era steam generator S-1114-111. This unit is considered to be a typical industry-wide example of BPS steam generator operation.

A. Basis and Assumptions

- All direct GHG emissions are the result of the combustion of natural gas in the steam generator.
- Maximum heat input rating of the steam generator is 85 MMBtu/hr
- Actual fuel consumption for the steam generator is 72.5 MMBtu/hr
- Heat output at 88.1% thermal efficiency = 63.9 MMBtu/hr
- The GHG emission factor for natural gas combustion is 117 lb-CO_2e/MMBtu (per CCAR document, see earlier assumptions)
- Air blower motor mechanical output when operated at 40.3 Hz is 110 hp
- Water pump motor mechanical output when operated at 56.1 Hz is 77.3 hp
- High efficiency electric motor efficiency = 95.8% (NEMA)
- Indirect emissions from electric power consumption are calculated based on the current PG&E electric power generation factor of 0.524 lb-CO_2e per kWh (see earlier assumptions)
- Steam quality = 70%
- Steam temperature = 524 F
- Mass flowrate = 1,683,234 lb·water/day
- Feedwater temperature = 115 F
- Convection surface area = 20,245 square feet

B. Calculation of Potential GHG Emissions per Unit of Activity (G_a)

1. Indirect GHG Emissions from Blower

Specific electricity consumption and GHG emissions for the high efficiency blower motor

110 hp x 0.746 kW/hp x (1/95.8%) x 0.524 lb·CO_2e/kW·hr = 44.9 lb·CO_2e/hr
44.9 lb·CO_2e/hr ÷ 63.9 MMBtu/hr = 0.703 lb·CO_2e/MMBtu (of heat output)

2. Indirect GHG Emissions from Water Pump

Electrical Consumption for the high efficiency water pump motor

77.3 hp x 0.746 kW/hp x 1/95.8% x 0.524 lb·CO2e/kW·hr = 31.5 lb·CO2e/hr
31.5 lb·CO2e/hr ÷ 63.9 MMBtu/hr = 0.493 lb·CO2e/MMBtu (of heat output)

3. Direct GHG Emissions

72.5 MMBtu/hr (heat input) x 117 lb·CO_2e/MMBtu = 8,483 lb·CO_2e/hr
8,483 lb·CO_2e/hr ÷ 63.9 MMBtu/hr = 132.8 lb·CO_2e/MMBtu (heat output)

4. Total BPS GHG Emissions (indirect emissions + direct emissions)

G_a = (0.703 + 0.493 + 132.8) lb·CO_2e/MMBtu = 133.996 lb·CO_2e/MMBtu (heat output)

G_a = 133.996 lb·CO_2e/MMBtu x 1 metric ton/2,205 lb
= 0.060769 metric tons·CO_2e/MMBtu (heat output)

C. Calculation of Potential GHG Emission Reduction as a Percentage of the Baseline Emission Factor (G_p)

G_p Indirect = (BEF - G_a) ÷ BEF metric tons/MMBtu
G_p Indirect = (0.000882 - 0.000542) ÷ 0.069816 = 0.00487 = 0.49%

G_p Direct = (BEF - G_a) ÷ BEF metric tons/MMBtu
G_p Direct = (0.068934 - 0.060227) ÷ 0.069816 = 0.124635 = 12.47%

G_p Indirect + G_p Direct = (0.000882 - 0.000542) ÷ 0.069816
+ (0.068934 - 0.060227) ÷ 0.069816

G_p Indirect + G_p Direct = 12.96 % = 13.0%

STEP 5. Rank all Achieved-in-Practice GHG emission reduction measures by order of % GHG emissions reduction

Based on the calculations presented in Section II.4 above, the Achieved-in Practice GHG emission reduction measures are ranked in the Table below.

Table 4
Ranking of Achieved-in-Practice GHG Emission Control Measures

Rank	Control Measure	Potential GHG Emission per Unit of Activity (G_a) (Metric Ton-CO_2e/MMBtu)	Potential GHG Emission Reduction as a Percentage of the Baseline Emission Factor (G_p)
1	6. Very high efficiency steam generator design with: 1. A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) **or** a manufacturer's overall thermal efficiency rating of 88%. **And** 2. Variable frequency drive high efficiency electrical motors driving the blower and water pump.	0.0608	13.0%
2.	1. High efficiency steam generator design with: A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) **or** a manufacturer's overall thermal efficiency rating of 88%.	0.060227	12.47%
3.	5. Variable frequency drive high efficiency electrical motors driving the blower and water pump.	0.000542	0.49%

STEP 6. Establish the Best Performance Standard (BPS) for this Class and Category

For Stationary Source Projects for which the District must issue permits, Best Performance Standard is – "For a specific Class and Category, the most effective, District approved, Achieved-In-Practice means of reducing or limiting GHG emissions from a GHG emissions source, that is also economically feasible per the definition of achieved-in-practice. BPS includes equipment type, equipment design, and operational and maintenance practices for the identified service, operation, or emissions unit class and category".

Based on the definition above and the ranking of evaluated technologies, Best Performance Standard (BPS) for this class and category is determined as:

<u>Best Performance Standard for Oilfield Steam Generators</u>

Very high efficiency steam generator design with:

1. A convection section with at least 235 square feet of heat transfer surface area per MMBtu/hr of maximum rated heat input (verified by the manufacturer) or a manufacturer's overall thermal efficiency rating of 88%.

And

2. Variable frequency drive high efficiency electrical motors driving the blower and water pump.

STEP 7. Eliminate All Other Achieved-in-Practice Options from Consideration as Best Performance Standard

The following Achieved-in-Practice GHG control measures identified and ranked in the table above are eliminated from consideration as Best Performance Standard since they have GHG control efficiencies which are less than that of the selected Best Performance Standard as stated in Step 6 of this evaluation.

Option 1. is eliminated because by itself it is not achieving the highest amount of GHG emission reductions. This option will be used in conjunction with variable frequency drive electrical motors driving the blower and water pump.

Option 5. is eliminated because by itself it is not achieving the highest amount of GHG emission reductions. This option will be used in conjunction with a high efficiency steam generator.

VI. Public Participation

A Draft BPS evaluation was provided for public comment. Public notification was sent on April 28, 2010 to individuals registered with the CCAP list server. The District's notification is attached in Appendix 5.

Comments received during the public notice period are presented in Appendix 6. These comments have been used in the development of this BPS as presented herein.

VII. Appendixes

Appendix 1:	Public Notice of Intent: Notice
Appendix 2:	Comments Received During the Public Notice of Intent and Responses to Comments
Appendix 3:	Public Participation Request for Information: Notice
Appendix 4:	Comments Received During the Public Participation Process and Responses to Comments
Appendix 5:	Public Notification: Posting of Draft BPS
Appendix 6:	Comments Received on Draft BPS and Response to Comments

Appendix 1
Public Notice of Intent (Issued 2/9/10)

San Joaquin Valley
AIR POLLUTION CONTROL DISTRICT

HEALTHY AIR LIVING

Notice Of Development Of
Best Performance Standards

NOTICE IS HEREBY GIVEN that the San Joaquin Valley Air Pollution Control District solicits public comment on development of Best Performance Standards for the following Stationary Source class and category of greenhouse gas emissions:

STEAM GENERATORS
Subject to District Rules 4301, 4304, 4305, 4306, 4307, 4308, 4351, 4352, 4401

The District is soliciting public input on the following topics for the subject Class and Category of greenhouse gas emission source:

- Recommendations regarding the scope of the proposed Class and Category (Stationary GHG sources group based on fundamental type of equipment or industrial classification of the source operation),
- Recommendations regarding processes or operational activities the District should consider when establishing Baseline Emissions for the subject Class and Category,
- Recommendations regarding processes or operational activities the District should consider when converting Baseline Emissions into emissions per unit of activity, and
- Recommendations regarding technologies to be evaluated by the District, when establishing Best Performance Standards for the subject Class and Category.

Information regarding development of Best Performance Standard for the subject Class and Category of greenhouse gas emission source can be obtained from the District's website at http://www.valleyair.org/Programs/CCAP/CCAP_idx.htm.

Written comments regarding the subject Best Performance Standard should be addressed to Steven Roeder by email, Steve.Roeder@valleyair.org, or by mail at SJVUAPCD Southern Region, 34946 Flyover Court, Bakersfield CA 93308 and must be received by **February 23, 2010**. For additional information, please contact Steven Roeder by e-mail or by phone at (661) 392-5615.

Information regarding the District's Climate Action Plan and how to address GHG emissions impacts under CEQA, can be obtained from the District's website at http://www.valleyair.org/Programs/CCAP/CCAP_idx.htm.

Appendix 2
Comments Received During the Public Notice of Intent and Responses to Comments

1. Comment - 2/22/10

In a telephone conversation with Dan Barber, Les Clark made comments regarding the development of BPD for Steam Generators. According to Dan,

> Les Clark expressed his opinions regarding development of BPS for steam generators. He was not specific in his concerns, but they seem to be he opposes the development of BPS because they will have a negative impact on independent producers. He thinks that implementing BPS could result in emission reduction requirements that are more stringent that required by current rules. Thus, the District is circumventing the exemptions/considerations that has been negotiated between his organization and the District. He stated that he has already expressed his concerns to Dave Warner and Seyed and that he guesses that he will have to address his concerns with the District's Board.
>
> I tried to get him to direct his comments to Steve Roeder, per the District's e-mail, but he responded that he did not have time for that and he had already told Dave, Seyed, and now me. So, I doubt that we will receive anything more than his verbal comments.

Response. The comments received were all considered in the drafting of the BPS document.

2. Comment - 2/23/10

John Ludwick of Berry Petroleum made the following comment via email.

> In my opinion the District can not receive adequate information to form BPS without first meeting with industry and their representatives to discuss what the baseline period equipment is. A blanket request for information will only create confusion and the submittal of information that can only be applied to a single company. Once the District understands the difference not only between industrial types, but the differences within the same industry, can the District begin receiving adequate information to form an achievable and economical BPS.
>
> ***Thank you,***
>
> *John Ludwick*
> ***Regulatory Compliance Specialist***
> ***Berry Petroleum Company***
> ***5201 Truxtun Avenue***
> ***Bakersfield, CA. 93309***
> ***Phone: (661) 616-3807***
> ***Cell: (661) 703-2920***
> ***Fax: (661) 616-3892***

Response: After receiving the attached comments, the District did hold meetings with WSPA and other oil industry representatives. Information received during and after the meeting was considered in the drafting of the BPS document.

Appendix 3
Public Participation Request for Information: Notice

The public participation notice was delivered via email to all of our subscribers on 2/25/10.

Dear Interested Parties:

The District needs your input in order to quantify "typical" greenhouse gas (GHG) emissions from Steam Generators that:
1) Operated during the "baseline period" from the years 2002 - 2004 , and
2) Have the lowest overall level of GHG emissions that is achieved in practice.

2 Sets of Requested Data

Please supply any data regarding any steam generators that:

1) Operated during the three year period from 2002 - 2004 (to determine the baseline GHG emissions), and

2) Data for steam generators that are currently operating the lowest level of GHG emissions, including the following.

   a. Steam generator ratings,
   b. Actual overall thermal efficiencies (heat output vs. heat input),
   c. Actual amount of electrical input (kilowatts or kilowatt hours) required (to determine the amount of GHG created by the generation of the electrical energy that is used by the steam generators),
   d. List of the equipment utilized with the steam generators (i.e. constant hp. electric motors, variable frequency drive motors, high efficiency motors, economizers of any kind, pre-heaters, etc.),
   e. Proposals for a method to quantify the emissions per unit of activity, either in lbs of GHG produced per unit of heat output, or lbs of GHG per unit of steam produced, or other method,
   f. Suggestions for defining the classes and categories of source, i.e. small producers, large producers, steam generators of a certain size range, etc., and
   g. Any other comments or data.

The data requested can be presented on any steam generators, as long as we have enough data to determine the overall GHG emissions per unit of activity.

Thank you for your cooperation in this matter.

In Addition:

The District is extending the initial commenting period regarding development of Best Performance Standards (BPS) for oilfield steam generators.

Comments must be received by the District by Thursday, March 4, 2010.

Thank you for your cooperation in this matter.

Steve Roeder
SJVAPCD
34946 Flyover Court
Bakersfield, CA 93308
(661) 392-5615

Appendix 4
Comments Received During the Public Participation Process and Responses to Comments

1. Comment - 3/2/10

Jim Mosher made the following comments via telephone. This is a record of that conversation:

> I spoke with Jim Mosher. He will be our representative from ERA. He presented a couple of interesting ideas.
>
> 1. If a company has access to hot feedwater, the amount of heat input required to heat the water might go down, but the stack temperature will be higher, indicating wasted heat and thus lower thermal efficiency.
> 2. Sometimes the Total Dissolved Solids can limit the amount of steam quality before they plug up your pipes. It sounds like you'd need to heat a lot more water to achieve the same thermal goal in this case.
>
> Jim said that he would be working with an engineer at ERA and would try to get us the data, not by March 4th, but by next week some time.

Response: The District indicated that input would be welcomed and would be taken into consideration.

2. Comment - 3/4/10

The following section of a more general email from Michael Kelley is applicable to steam generator BPS.

Attachment-II (of 3/4/10 e-mail)

Best Performance Standards for Steam Generators

A. Scope of the BPS for Steam Generators

The BPS for “Steam Generators” should be applicable to those steam generators located at crude oil and natural gas production and processing facilities; or located at other facilities where the primary purpose of the unit is the production and use of steam for a purpose other that the conversion to mechanical or electrical energy.

B. Calculation Procedures

For a discussion on the procedures used for calculating GHG emissions for the purpose of CCAP and BPS see Attachment-I.

C. GHG BPS Factors per Unit of Production

We believe that for oilfield steam generators the most appropriate unit of production factor for GHG emissions should be derived from the mass emissions (pounds) of GHG per barrel of steam. Baseline emissions would be calculated from historic production records (10 year look back) and historic steam-to-oil production ratios.

D. Controls and Design Changes for Steam Generators

We are opposed to the BPS examples included in the CCAP adopted by the District on December 17, 2009. As discussed previously we believe that a menu approach should be used for applying BPS to project. We believe that operators should receive credit for the types of activities:

1. Provide fuel saving credit for preheating feed water or using feed water having a temperature greater than the ambient temperature.
2. Provide fuel saving credit for improvement in process efficiency brought about by the redesign of steam generator convection systems.

Response: All of these suggestions have been taken into account in preparing the Steam Generator BPS.

3. Comment - 3/11/10

Keith Jones of Seneca Resources submitted the following data along with the following spreadsheet detailing steam generator GHG emissions.

From: Keith Jones
Sent: Thursday, March 11, 2010 4:40 PM

Tim,

As requested two moons ago here is my evaluation of energy usage improvements we have made in steam generator operation. The evaluation was based on a comparison of the B&R Generator placed on line in June 2009 with the HP 7 generator using data collected on 3/8/10.

1) Thermal efficiency has been improved by 11.1% by installing 167% more surface area in the convection box (or economizer).
2) Electrical demand by the pump motor has been reduced by:
    a. Installing a VFD to eliminate the need to by-pass water from the pump discharge to it's suction. Annual savings of 30,719 KW-H.
    b. Utilizing the split flow design so half the water is directed to each half of the radiant section and convections sections results in a reduction of the pump discharge pressure by up to 220 psi. Annual savings of 132,042 KW-H.
    c. Increasing the pump discharge piping size from 3" to 4" upstream of the split. Annual savings of 884 KW-H.
3) Electrical demand by the blower motor has been reduced by installing a VFD to control excess oxygen in the combustion chamber instead of using louvers and restrictor plates. Annual savings of 130,736 KW-H.
4) Installing higher efficiency motors on both the pump and blower results in an annual savings of 18,384 KW-H.

Thermal Efficiency, useful heat out / heat in

Steam Gen.	Burner rating, MMBTU/HR	Convection box, type	Convection, surface area, sq.ft.	Date installed	Date	Heat IN, MMBTU/HR	Heat Out, useful MMBTU/HR	**Thermal Efficiency, Heat out / heat in, %**	Steam Quality, %	Average pressure, psig	Feedwater temp., °F	Stack temp., °F	Fuel rate, MCFD (1,023 BTU/CF)	BWPD	lbm/day	Heat Enthalpy in steam, BTU/day	Feedwater IN, BTU/day	Net useful heat out, BTU/day
S-1114-16 (HP7)	62.4	pyramid	7590	1981	3/8/2010	56.4	43.4	**77.0%**	70	943	132	328	1322	3,367	1,162,144	1,158,053,648	116,186,548	1,041,867,100
S-1114-111 (B&R)	85	lay down	20245	Jun-09	3/8/2010	72.5	63.9	**88.1%**	70	825	115	229	1701	4,855	1,683,234	1,672,326,283	139,716,808	1,532,609,475
		% Increase	62.5%															

Pump Motor power savings from VFD

Steam Gen.	Motor size	RPM	NEMA, Nom. Eff.	Pump Rate control	Pump, RPM @ 60 HZ	Pump's theo. Rate, BPD at 60 Hz	Date	Pump discharge pressure, psig	Input Hz to pump	Input HHP	Input BHP	Output HHP	Output BHP	Extra power usage, BHP	Extra power usage, KWH/HR
S-1114-16 (HP7)	100	1780	95	By-pass water from Discharge to suction	347.1	3,582	3/8/2010	1155	60.0	70.4	78.2	66.2	73.5	5	3.5
S-1114-111 (B&R)	200	1200	95.8	VFD	352	5,193	3/8/2010	935	56.1	77.3	85.9	77.3	85.8	0	0.0
												annual power savings due to VFD, KW-H			**30,719**

Pump Motor power savings from split flow

Steam Gen.	Tube size, Nom. I.D. inches	Flow rate, BPD	Pressure drop, psi per 100 feet	Convection box, tube #	Radiant section, tube #	Total Length, pipe ft	Date	Pump discharge pressure, psig	System, pressure drop if in water phase	HHP	BHP	Extra power usage, KWH/HR	**Power savings per year, KW-H**
S-1114-16 (HP7)	2.9	3,367	1.329	50	64	4770	3/8/2010	1155	63.3933	3.6	4.0	3.0	
S-1114-111 (B&R)	2.9	2,427	0.69	109	32	4485	3/8/2010	935	30.9465	1.3	1.4	1.1	
		4,855	pump discharge pressure difference due to pipe friction, two phase (saturated steam) flow						220	18.2	20.2	15.1	**132,042**

Pump Motor power savings from increasing discharge pipe size:

Additional capital is spent to install a 4" line on the discharge of the pump instead of 3" pipe.

Steam Gen.	Tube size, Nom. I.D. inches	Flow rate, BPD	Pressure drop, psi per 100 feet	Total Equivalent length, ft	System, pressure drop, psi	HHP	BHP	power usage, KWH/HR	power usage, KWH/ year
S-1114-111 (B&R)	2.9	4,855	2.763	77.3	2.1	0.2	0.2	0.1	1,282
S-1114-111 (B&R)	3.826	4,855	0.691	95.9	0.7	0.1	0.1	0.0	398
						Power savings per year, KW-H			**884**

Blower Motor power savings from VFD

With the use of the ultra low Nox burners control over the % O2 in the combustion chamber is critical to meet the Nox and CO emission limits. VFD are used to provide the right volume of air and FGR to meet the emissions levels. Since louvers and restrictor plates are not used the investment in the VFD reduces the power usage.

Steam Gen.	Nameplate blower motor, HP	BHP @ 60 HZ, see blower curve	Hz to blower motor, 3/10/10	Combustion air volume, CFM	BHP @ 40.3 HZ, see blower curve	Power savings, KWH / HR
S-1114-111 (B&R)	150	130	40.3	16,935	110	14.9
			Power savings per year, KW-H			**130,736**

Motor power savings from efficiency

When new Generators are installed the most efficient motors available are purchased.

Date	Nom. NEMA efficiency, %	BHP, blower plus pump, S-1114-111	power usage, KWH/HR	input power, KWH/HR
before 2003	94.5	196	146	154.5
after 2003	95.8	196	146	152.4
	Power savings per year, KW-H			**18,384**

H:\My Documents\SR MEMORY\Green House Gasses\Steam Generator Efficiency Calculations for APCD March 2010.xls

by: Seneca
K. Jones
8 March 2010

Eff. Calc.

Response: Some of the figures presented have been taken into account in this BPS evaluation.

4. Comment - 3/16/10

John Kerchinski of PCL made the following comment via email:

> The majority of steam generators built prior to 2002 are remnants of oil fired days. These units typically have very inefficient convection sections to keep the exhaust temperatures above sulfur dew points. As most steam generators are now gas fired, acid dew points are not a concern and convections have been designed to increase thermal efficiency. Pre 2002 units are in the 80% range and our newest designs are in the 90 – 91% range.
>
> Hope this helps.
>
> John Kerchinski

Response. This information has been taken into account in preparing the Steam Generator BPS. As clearly outlined in Section III.C above, the temperature of the feedwater effects the overall maximum achievable efficiency of the steam generator. In other words, an otherwise identical steam generator with a feedwater temperature of 70°F will have a higher efficiency than the same unit with a feedwater temperature of 115° F. Note, however, that even though the thermal efficiency of the first unit will be higher, the overall heat requirement, and thus the overall GHG emissions will be lower for the second unit, because it does not have to heat the water as much to produce the same quality of steam. Therefore, the Unit of Activity defined on Page 8 above is based on GHG emissions per unit of heat output.

In addition, due to the technical impracticalities and non achieved-in-practice status of obtaining 91% thermal efficiencies out of steam generators that may have extremely high feedwater temperatures, we have determined the mechanism through which the highest efficiency has been attained in an oilfield steam generator. Since 235 square feet of convection section heat exchanger surface area is the equipment that reaches the high efficiency level, the equipment just described will be included as an equipment alternative to the 88% thermal efficiency for BPS.

Appendix 5
Public Notice: Posting Draft BPS

The San Joaquin Valley Air Pollution Control District is soliciting public comment on the development of Best Performance Standards (BPS). This email is to advise you the draft BPS document for Steam Generators is now available for review here.

Written comments should be addressed to Steve Roeder by email, Steve.Roeder@valleyair.org or by mail at SJVUAPCD, 34946 Flyover Court, Bakersfield, CA 93308 and must be received by **May 21, 2010**. For additional information, please contact Steve Roeder by e-mail or by phone at (661) 392-5615.

Appendix 6
Comments Received on Draft BPS

1. Comment - May 17, 2010

Timothy Alburger of Seneca Resources commented via email:

> With regard to the most-recent BPS for steam generators, the District may want to revise *bare tubes* to “extended tube surface area,” which includes the bare tubes plus the fins.
>
> Timothy R. Alburger
> EHS Manager
> Seneca Resources
> 2131 Mars Court
> Bakersfield, CA 93308
> Telephone: 661.399.4270, ext. 3544
> Cell Phone: 661.619.9926
> Fax: 661.399.7706
> E-mail: alburgert@srcx.com

Response. After specific research, it was confirmed that the original steam generator from which our figures were gathered was made with fins (see BPS Document). Therefore, the “Fin” surface area concept has been addressed in the BPS document.

2. Comment - May 30, 2010

Bob Poole of WSPA Commented via email:

Hi Steve:
Please find below WSPA's comments on the SJVAPCD GHG BPS for Oilfield Steam Generators. We believe the edits and clarification of the proposed BPS language will enhance the final version of the BPS document.

WSPA Comments

- To allow for vertical or horizontal convection section design and to correctly characterize that convection surface area, WSPA requests that the Control Measure 1 Qualification be modified as follows:
"Convection section with at least 235 square feet of bare and/or equivalent extended surface area per MMBtu/hr of heat input…"
- In the BPS, it should be clear that thermal efficiency calculations are based upon "higher heating value (HHV)" and fuel measurements are on a "gross, dry basis" (consistent with utility recording protocol).
- The PG&E "electric power generation factor" on page 4 should be have a specific citation.
- On page 10, it should be noted that while SCR does reduce NOx emissions without the need for extensive FGR, it also results in higher resistance (delta-P) which offsets some of the energy efficiency gains attributed to the reduced FGR requirement.

Thank you for your consideration of these comments and we look forward to continued work with the District on BPS.
Bob
Bob Poole
Manager, Production Regions and State Waste Issues
Western States Petroleum Association
901 Tower Way, Ste. 300
Bakersfield, Ca 93309
Tel: (661) 321-0884 Fax: (661) 321-9629
Mobile: (805) 252-6778

Response. These comments have been taken into account in the final Steam Generator BPS document.