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Discussion of Gross Energy Heat Rate for Proposed Combustion Turbine/ Heat Recovery System
Proposed Greenhouse Gas Permit for Liquefaction Project
Freeport LNG Development, L.P.
PSD Permit Number PSD-TX-1302-GHG

Freeport LNG is submitting the following information to the U.S. Environmental Protection Agency (EPA) Region 6 in support of the Statement of Basis for the Draft Prevention of Significant Deterioration (PSD) Permit for Greenhouse Gas Emissions for Freeport LNG's proposed Liquefaction Plant to be located in Brazoria County, Texas. Freeport LNG previously submitted a discussion of gross energy heat rate for the combustion turbine system associated with the proposed Pretreatment Facility to the EPA by letter dated 14 March 2013. The following is intended to provide a more thorough discussion of the degradation factors used in the development of the adjusted net heat rate for the proposed combustion turbine system. It is requested that this updated information be incorporated into the Draft Statement of Basis to be published in support of the Draft GHG PSD Permit for this project.

For the combustion turbine, Freeport LNG is proposing an output-based CO_2 limit based on equivalent useful energy produced of 738 pounds CO_2 per megawatt-hour. This is based on an adjusted Gross Combustion Turbine Energy Heat Rate of 5,210 Btu per kilowatt-hour (Btu/kWh) after allowances for design margins and initial and long-term degradation in equipment performance. A summary showing the basis for the proposed equivalent useful energy output-based limit is shown in the attached Table 1.

The combustion turbine proposed by Freeport LNG for the Pretreatment Facility is being installed in a combined heat and power (CHP) configuration. Since the combustion turbine exhaust energy is being recovered and harnessed for use along with electrical energy from the generator, more of the fuel burned in a CHP application is recovered as useful energy than in a simple-cycle combustion turbine application. As such, and in order to calculate the energy output-based BACT limit, lb CO_2/MWh, in any meaningful way, the useful thermal energy recovered from the combustion turbine exhaust must be added to the combustion turbine net electrical output to determine the <u>total useful energy</u> recovered from burned fuel. This is the same methodology that requires the electrical output of a steam turbine be added to the electrical output of the combustion turbine in order to arrive at the total useful energy recovered in a combined-cycle combustion turbine application. In the case of CHP proposed for the Pretreatment Facility, the useful thermal energy recovered from the combustion turbine exhaust converted to the same unit of measure, kW, as the combustion turbine electrical output is analogous to the steam turbine electrical output.

As summarized in Table 1, the useful process thermal energy recovered from the PTF combustion turbine exhaust, in MMBtu/hr, was converted to an equivalent value in kW, as follows:

406 MMBtu/hr x 1,000,000 Btu/MMBtu x kW-hr/3415 Btu = 118,887 kW equivalent

Combining the net electrical energy output of the combustion turbine with the equivalent value for the combustion turbine exhaust energy recovered:

84,409 kW (net combustion turbine electrical energy output) + 118,887 kW equivalent
= 203,296 kW (equivalent net electric and useful thermal energy output recovered)

Expressing performance in terms of heat input per kilowatt-hour:

906.2 MMBtu/hr (LHV) x 1,000,000 Btu/MMBtu / 203,296 kW
= 4458 Btu/kWh (gross combustion turbine energy heat rate)

To establish an enforceable BACT condition that can be achieved over the life of the facility, the output-based CO_2 limit must account for short-term degradation in performance as the unit is installed, brought on-line, and commissioned; anticipated degradation of the combustion turbine over time between regular maintenance cycles; and potential degradation of other elements of the system over time. Therefore, the following compliance margins are added to the base heat rate limit:

- A 5 percent design margin reflecting the possibility that the constructed facility will not be able to achieve the design heat rate.
- A 6 percent performance margin reflecting efficiency losses due to equipment performance degradation between maintenance overhauls.
- A 5 percent degradation margin reflecting the degradation of auxiliary plant equipment due to use over time.

A new power plant that is designed, constructed and commissioned properly should be able to operate at the design power and heat rate guaranteed by the supplier. However, the design of a CHP system incorporates many assumptions regarding anticipated performance of the many elements of the plant that are often not reflective of installed operating conditions. To allow for this occurrence, Freeport LNG estimated a 5 percent design margin to address such items as equipment underperformance (based on contractor design margins) and measurement uncertainty, estimated to be 3.5 percent and 1.5 percent, respectively.

In addition, the power plant's overall performance will gradually decrease over time due to degradation of the plant's components. Degradation is due to wear and tear during operation, startup and shutdown due to contaminants in the fuel or combustion air to the system. Therefore, the BACT limit must also account for anticipated degradation of equipment over time between regular maintenance cycles. Gas turbine degradation can be classified as recoverable or non-recoverable over time. Recoverable loss is usually associated with deposition and compressor fouling and can be partially recovered by water washing or mechanical cleaning of the compressor blades and vanes. Non-recoverable loss is due primarily to wear and tear of machine components, aging, erosion, corrosion, etc., resulting in increased turbine and compressor clearances and changes in surface finish and airfoil contour. This type of loss is recovered through replacement of affected parts at recommended inspection intervals. Based on literature review of axial compressor performance, performance degradation during the first 30,000 hours of operation is estimated to be about 2-6 percent from the performance test measurements when corrected to guaranteed conditions.[1] These degradation rates may be used as benchmarks, but may not represent the actual degradation rate between major overhauls or through the unit's operational life. Even with replacement of degraded parts, the expected performance degradation is from 2-3 percent in capacity in the first year of service, followed by about another 3 percent loss over the next five years[2]. Another study by VY Consult presents a discussion of losses due to degradation for the gas turbine inlet (0.8-1.6 percent), compressor degradation (0.8-4.4 percent) and power turbine degradation (0.4-1.9 percent) for an overall degradation for the combustion turbine of about 2-7.9 percent.[3] For purposes of establishing a BACT condition that can be achieved over the life of the proposed combustion turbine, a 6 percent margin was incorporated into the determination of the adjusted net heat rate to account for performance degradation over the life of the unit.

In addition to recoverable and non-recoverable degradation of the combustion turbine, degradation of the combustion turbine's waste heat recovery system caused by tube fouling, thermal degradation, etc., as well as the other elements of the Pretreatment Facility that

[1] Norwegian University of Science and Technology, *Axial Compressor Performance Deterioration and Recovery through Online Washing*, Elisabet Syverud, May 2007.
[2] EPRI, *Axial Compressor Performance Maintenance Guide Update*, February 2005.
[3] VY Consult (Consulting Engineers), Malaysia, *Combined Cycle Power Plant Performance Degradation*, PowerGen Asia, Sept 2008.

depend on the waste heat recovery system (e.g., amine regeneration units) that can potentially cause the overall plant heat rate to rise were also considered. If considered analogous to a heat recovery steam generator, the waste heat recovery system alone could experience from 1.1-5.6 percent degradation due to scaling and increased wall temperatures.[3] To allow for possible degradation of this associated equipment, a 5 percent margin was incorporated into the determination of the adjusted net heat limit rate.

These additional margins were combined with the Gross Combustion Turbine Energy Heat Rate to arrive at the Adjusted Gross Combustion Turbine Energy Heat Rate of 5210 Btu/kWh, as follows:

4458 Btu/kWh x (1 + 0.05) x (1 + 0.06) x (1 + 0.05) = 5210 Btu/kWh

As a frame of reference, the Gross Combustion Turbine Energy Heat Rate for Freeport LNG's proposed CHP unit was compared to the Gross Combustion Turbine Energy Heat Rate for a CHP as proposed by the EPA in its recent Draft GHG Permit for Air Liquide Large Industries U.S., L.P. Bayou Cogeneration Plant.[4] In this draft permit, the Gross Combustion Turbine Energy Heat Rate proposed as BACT for each CHP is 7720 $Btu_{(HHV)}/kWh_{(gross)}$ equivalent based on a 365-day rolling average.

On the basis of total useful energy recovered in exchange for fuel consumed, the Adjusted Gross Combustion Turbine Energy Heat Rate for Freeport LNG's proposed CHP is essentially 32.5 percent lower than the value proposed for the Air Liquide CHP, as follows:

(7,720 – 5210)/7720 = 32.5 percent

When total useful energy recovered is properly taken into consideration, Freeport LNG's selection of CHP for its combustion turbine installation very much validates the EPA website statement on CHP:

> "Because less fuel is burned to produce each unit of energy output, CHP reduces air pollution and greenhouse gas emissions."[5]

[4] U.S. EPA, *Draft Permit Prevention of Significant Deterioration Permit for Greenhouse Gas Emissions, Air Liquide Large Industries U.S., L.P.*, August 2013

[5] http://www.epa.gov/chp/basic/, accessed November 7, 2013.

Table 1

Calculation of Output-Based BACT CO_2 Limit
Pretreatment Facility - Combustion Turbine/Waste Heat Recovery System
Freeport LNG Development, L.P.

Manufacturer	General Electric	
Combustion Turbine	Frame 7EA	
CT Cycle Operating Mode	CHP	
CT Inlet Dry Bulb, F	60	
Gross CT Power Out, kW	87,470	Note: CT Performance from Manufacturer's Data
CT Fuel Input, MMBtu/hr LHV	906.2	
Process Thermal Energy Required, MMBtu/hr	406	
Process Thermal Energy from CT Exhaust, MMBtu/hr	406	
Process Thermal Energy from CT Exhaust, kW	118,873	
Fired Heater Fuel Input, MMBtu/hr LHV	-	
CT Plant Auxiliary Loads, kW (estimated)	(3,061)	-3.5% percent of gross output
Net CT Plant Electrical Output, kW	84,409	
Total Useful Energy Produced, MMBtu/hr	694	Note: Includes net electrical and process thermal output
CT Plant Thermal Efficiency	76.6%	
Gross CT Energy Output, kW equivalent net electric and useful thermal converted to kW	203,281	
Gross CT Energy Heat Rate, Btu/kWh	4,458	CT Fuel Input / Gross CT Energy Output
Design Margin	0.05	Allowance for equipment underperformance and measurement uncertainty.
Performance Margin	0.06	Allowance for loss of plant efficiency due to normal and expected gas turbine performance degradation between overhauls
Degradation Margin	0.05	Allowance for degradation of other elements of the Pretreatment Facility that could cause overall combustion turbine heat rate to rise
Adjusted Gross CT Energy Heat Rate with Compliance Margin, Btu/kWh	5,210	Gross CT Energy Heat Rate * (1 + 0.05) * (1 + 0.06) * (1 + 0.05)
CO_2 tons/hr	64.17	Estimated based on Mandatory Greenhouse Gas Reporting Rule, 40 CFR Part 98, Subpart C, Table C-1 for Natural Gas
CO_2 lb/hr	128,340	
CO_2 lb/MMBtu	141.62	CO_2 lb/hr / CT Fuel Input (LHV)
Proposed Output-based CO_2 Limit, lb CO_2/MWhr equivalent useful energy produced	738	Based on Gross CT Energy Output, MW ()