



## VOC Emissions from LM6000 for Mariposa Energy, LLC

This memo is with reference to the proposed VOC BACT standards for 4xLM6000 PC Sprint engines for the Mariposa Energy project. Based on Preliminary Determination of Compliance for the Marsh Landing Generating Station, BAAQMD is proposing an emissions limit of 1 ppmv for VOC emissions at the stack. This document explains GE's position with respect to gas turbine VOC emissions.

### Executive summary

1. The high operational flexibility of aeroderivative gas turbines is well suited to meet growing peaking and cycling needs in the power generation sector with high penetration of renewables.
2. High pressure-ratio Aeroderivative gas turbines with their high simple cycle efficiency produce lowest CO<sub>2</sub> emissions on a lb/MWh basis leading to low CO<sub>2</sub> footprint.
3. In arriving at BACT for CO and VOC emissions, it is important to take into consideration differences in technologies between Aeroderivative and HD frame gas turbines.
4. Consideration of VOC levels in ambient air that bypasses the combustion system is critical to limiting VOC emissions from the stack. Use of filters is not sufficient to remove the VOC's from ambient air that bypasses the combustion system and ambient VOC levels affect exhaust stack VOC concentrations.
5. For VOC emissions, state-of-the-art catalyst systems are able to achieve only limited reduction in VOC's. Higher efficiencies with Aeroderivatives lead to lower exhaust temperatures, which limit the degree of reduction in VOC's that can be achieved using catalysts.
6. At low ppm (1-2 ppm) levels, errors in measurement and sampling methods for VOC emissions cannot be ignored in arriving at BACT levels. The permitted emissions levels need to account for variations in sampling, measurement method, engine-to-engine variation, ambient and load conditions.

The LM6000PC is a gas turbine engine derived from GE's proven CF6-80C2 aircraft engine. Aeroderivative engines such as the LM6000 have several distinguishing features. The LM6000 has a 2-shaft architecture that permits the low speed shaft to continuously rotate at 3600 rpm while the airflow and the high-pressure-turbine shaft speed modulate with power. Aeroderivative engines also have higher operating pressure ratios (OPR 28-30). The higher pressure-ratios result in a greater pressure drop and consequently greater temperature drop across the turbines. Thus, while the

firing temperatures of the Aero-derivative engines are comparable to Heavy Duty (HD) Frame engines, the higher temperature drop results in a lower exhaust temperature for Aero-derivative engines. These unique features of Aero-derivative gas turbines result in a superior simple-cycle efficiency (40-44%) with unmatched operational flexibility (10min start, 30 MW/min ramp rate). The lightweight components enable the Aero-derivative gas turbines to sustain multiple starts per day without maintenance penalties, greater turndown, and faster ramp rate to meet demands in power. These features are directly attributable to the aviation heritage.

In simple cycle configuration Aero-derivatives have achieved high-energy efficiencies due to the higher pressure-ratios. This also leads to lower CO<sub>2</sub> (Green house gases) emissions on a lb/MWh basis as shown in Fig. 1. The higher operational flexibility of Aero-derivatives is ideally suited to meet increased cycling and peaking requirements associated with integration of intermittent renewable energy.

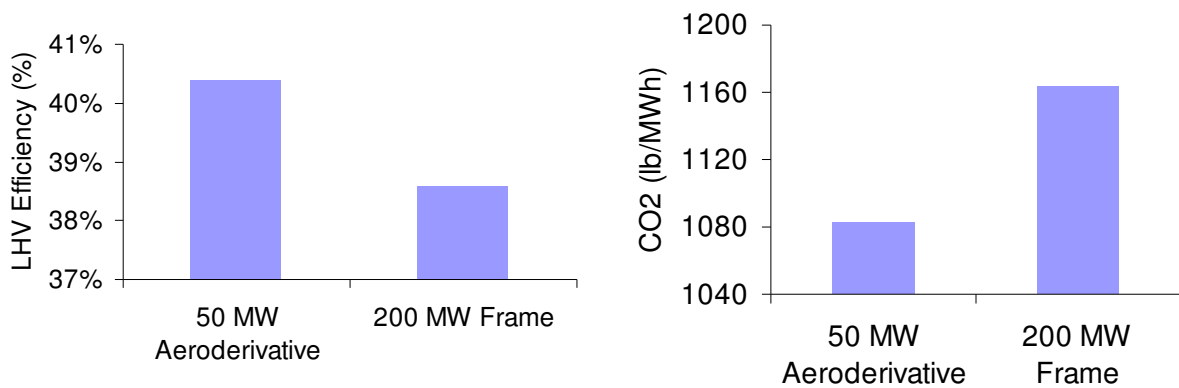


Fig.1: Comparison of thermal energy and efficiencies and CO<sub>2</sub> emissions achievable with Aero-derivative gas turbines and 200 MW HD frame gas turbines in simple cycle mode.

Aero-derivative and HD frame gas turbines have evolved with different design philosophies. Aero-derivative gas turbines have been derived from flight engines and are optimized for high simple-cycle efficiencies and flexible operation. The design heritage based on flight requirements provides for limited space for the combustion system and hence these engines have typically used annular combustor designs with residence times in the 3 to 5 millisecond range. HD frame gas turbines in general have been designed for higher combined-cycle efficiencies and consequently operate at lower pressure ratios and lower simple-cycle energy efficiency than Aero-derivative gas turbines. Since HD frame gas turbines have been designed for land-based applications, they are typically heavier and also have lower output per unit mass flow of air than Aero-derivative gas turbines. The combustion systems in HD frame machines are typically of the can-annular type with residence times on the order of tens of milliseconds. While both types of gas turbines have their unique strengths, Aero-derivative gas turbines are ideally suited for simple cycle applications with unmatched operational flexibility requirements such as in peaking power, while maintaining best in class efficiency. Due to different design philosophies, there are some fundamental differences in achievable emissions between these two types of gas turbines.

Pollutants such as NO<sub>x</sub> and CO are formed in the combustor of these high performance engines as a byproduct of the combustion of fuels. NO<sub>x</sub> (actually several Nitrogen oxide species) is formed by the oxidation of Nitrogen at high temperatures in the flame zone of the combustor. CO is generally formed in the flame front and burns away as excess air is added to the hot gasses from the flame front. The LM6000 PC utilizes water injection in the combustor to lower NO<sub>x</sub> emissions from the gas turbine. Further reductions of NO<sub>x</sub> emissions are achieved with the use of Selective Catalytic Reduction (SCR) systems in the exhaust stream that use ammonia to reduce NO<sub>x</sub> chemically into nitrogen and water. CO emissions are reduced using noble metal catalysts in series with the NO<sub>x</sub> catalyst. Methane and ethane are major fuel components and are commonly found in extremely small quantities in gas turbine exhausts. Other non-methane/ethane species have also been measured in gas turbine exhausts in trace quantities<sup>1</sup>. These hydrocarbons, other than methane and ethane, constitute what are referred to as 'Volatile Organic Compounds' (VOC's).

In areas that have high ambient concentrations of Unburned Hydrocarbons (UHC's) and VOC's, ambient VOC levels should be assessed (using the same measurement methods) for contribution to stack measurements. In addition, when reviewing the air-flow of the LM6000 in combination with an SCR/COR system, one will observe that a substantial portion of the exhaust stack air will not go through the combustion process. The sources of ambient air bypassing the combustion process are:

- 1) Turbomachinery Cooling Air: Modern gas turbines are cooled by air bypassing the combustion process and directed to disks, blades and other parts requiring cooling. The cooling air in an LM6000 does not enter the combustion zone and constitutes approximately 30% of all air entering the gas turbine.
- 2) Ammonia Carrier Air: When considering the addition of ammonia into the SCR at the exhaust stream of the gas turbine, one must consider the ammonia and its carrier (ambient air) have not been through the combustion process.
- 3) Exhaust Gas Tempering Air: The tempering air that cools the exhaust gas and enters upstream of the SCR catalyst is drawn from the ambient and makes up approximately 10% of the total exhaust-stack mass flow.

Although the combustion process should eliminate the ambient VOC taken in through the inlet, the VOC from ambient air taken in for cooling and tempering purposes contributes to the VOC emissions from the stack. Use of filters is not sufficient to remove the VOC's from ambient air contributing to emissions at the stack.

An LM6000 PC equipped with an SCR (for NO<sub>x</sub>) and oxidation catalyst (for CO) is well suited for compliance with strict regulations promulgated in California. The oxidation catalysts (generally noble metals on alumina substrate) are designed to oxidize greater than 70%-90% of the CO in the exhaust stream at full power. Conversion of hydrocarbons is dependant on catalyst used, residence times and temperatures in the catalysts. Hydrocarbon conversion has been reported from 10-40% for these catalysts<sup>2</sup> depending on the exhaust temperatures achieved. For the high efficiency Aeroderivatives the exhaust temperature is typically lower than HD frame gas

turbines due to the differences in cycle thermodynamics. This means that a VOC catalyst system cannot achieve the same level of conversions. It is necessary to take this difference into consideration when arriving at BACT limits for VOC's.

Finally, measurement uncertainty must be considered for low levels of VOC emissions. Several EPA<sup>3</sup> and District methods have been used to measure trace quantities of VOC's. The non-methane, non-ethane VOC's are regulated by local, state and federal air quality regulations in several areas. The separation of these non-methane and non-ethane components from the exhaust stream of gas turbines can only be achieved by the use of gas chromatography. Different methods have been used in the past to measure VOC's beginning with EPA method 18 and method 25 A, SCAQMD's method 25.3, and the method commonly used for gas turbines in the BAAQMD, a combination of EPA method 18 and EPA Compilation method TO-12. The commonly used BAAQMD VOC sampling and analysis method extracts gas sample into an evacuated SUMMA canisters via stainless steel probe and flow meter. EPA method 18 (Gas Chromatograph/Flame Ionization Detector) are used to determine VOC's concentrations of the sample. Although this measurement technique has significantly improved potential measurement/analytical techniques, errors in obtaining the sample from the field remains. In general, at the low concentrations (<2 ppm) that are being requested, minor errors with handling and cleaning of the sampling system can contribute to corruption of the data. In the past<sup>3</sup>, this was confirmed by significant variation between site-to-site and sample-to-sample data. At low ppm (1-2 ppm) levels, errors in measurement and sampling methods for VOC emissions cannot be ignored in arriving at BACT levels.

In summary, the following aspects need to be considered in coming up with permitted emissions levels for VOC:

- Simple cycle Aeroderivative engines have higher energy efficiency and lower carbon footprint than HD frame gas turbines.
- Higher simple cycle Aeroderivative engines due to their design heritage have unmatched operational flexibility.
- The aviation heritage and design considerations to achieve higher efficiencies and flexibility have required smaller combustors with shorter residence times and lower exhaust temperatures.
- Shorter residence times and lower exhaust temperatures limit the degree of reduction in CO and VOC that can be achieved.
- Inlet air bypass for cooling gas turbine and catalysts does not destroy ambient VOC's and these can bias stack VOC levels.
- Repeatable measurement of VOC's at these low levels is a challenge due to uncertainties in measurement and sampling systems.

Considering the above, GE believes that the BACT level of 1 ppm is too low to be practically achieved and measured on a consistent basis.

### **References:**

1. "Unburnt Hydrocarbon, Volatile Organic Compound, and Aldehyde Emissions from General Electric Heavy-duty Gas Turbines", Roointon Pavri and Richard Symonds. ASME 90-GT-279.

2. [http://www.johnzink.com/products/therm\\_ox/pdfs/tp\\_catalytic.pdf](http://www.johnzink.com/products/therm_ox/pdfs/tp_catalytic.pdf)
3. EPA websites for EPA Methods 18, 25A, 301  
(<http://www.epa.gov/ttn/emc/promgate.html>)
4. [www.agmd.gov/bact/minutes9-16-99.html](http://www.agmd.gov/bact/minutes9-16-99.html) for SCAQMD Scientific Review Committee Meeting #9 minutes recorded on 9/16/1999.