MEMORANDUM

DATE: October 31, 2024

SUBJECT: Fuel-Based F-Factors for Firing of Hydrogen and Hydrogen Blends in Combustion Turbines

FROM: Robert Bivens
Measurement Policy Group, SPPD

TO: Combustion Turbine Docket
Review of New Source Performance Standards for Stationary Combustion Turbines and Stationary Gas Turbines
40 CFR Part 60 Subpart KKKKa
EPA-HQ-OAR-2024-0419

Fuel dependent F-factor corrections (i.e., the ratio of the gas volume of the products of combustion to the heat content of the fuel) of pollutant concentrations to an emission rate are well known in the environmental and stack testing communities, and are described in detail in 40 CFR Part 60, Appendix A,. EPA Reference Method 19 (EPA Method 19).

However, in a white paper published by the Georgia Tech Strategic Energy Institute,[1] concerns were raised that the combustion research community, which is currently evaluating low NO_x combustion technologies with results that are being used by a wide variety of stakeholders in evaluating the benefits of combusting hydrogen in turbines, is often not applying F-factor corrections and hence is improperly comparing measured NO_x ppm emissions between one fuel and another. By applying an F-factor correction to the measured NO_x ppm concentrations, a consistent and uniform comparison between NO_x mass emissions in terms of lb/MMBtu on a fuel specific basis can then be made.

This is especially paramount since, under the proposed NSPS Subpart KKKKa rule, for new, modified, and reconstructed stationary combustion turbines that fire or co-fire hydrogen with natural gas, the EPA is proposing to ensure that those sources are subject to the same level of control for NO_x emissions as sources firing natural gas or non-natural gas fuels, depending on the percentage of hydrogen fuel being utilized.[2]

This memorandum describes the process that was used to develop the appropriate F-factors to be used as well as the calculation to convert NO_x ppm to NO_x lb/MMBtu when combusting either pure hydrogen or hydrogen/natural gas blends in combustion turbines.

[1] "NO_x Emissions from Hydrogen-Methane Fuel Blends", Georgia Institute of Technology and Electric Power Research Institute (January 2022).

[2] Specifically, the EPA is proposing that affected sources that burn less than or equal to 30 percent (by volume) hydrogen (blended with methane) should be categorized as natural gas-fired combustion turbines and subject to the same NO_x standards (in lb/MMBtu) as combustion turbines burning natural gas. For combustion turbines that burn greater than 30 percent (by volume) hydrogen (blended with methane), the EPA is proposing to categorize these sources as non-natural gas-fired combustion turbines and the applicable NO_x limit is proposed to be the same as the standard (in lb/MMBtu) for non-natural gas-fired combustion turbines.

A. F-factor Development for Hydrogen

Since NO_x emissions from a turbine are typically measured on a dry basis, and since there is no carbon present or carbon dioxide produced with the combustion of hydrogen, only an oxygen-based F-factor on a dry basis (F_d) is necessitated to be developed for the purposes of this memo.

To determine the F_d-factor for combusting hydrogen, Equation 19-13 of Method 19 is used:

$$F_d = \frac{K\,(K_{hd}\%H + K_c\%C \; + K_s\%S \; + K_n\%N - K_o\%O)}{GCV}$$

During hydrogen combustion, since hydrogen is the only component in the fuel being combusted, Equation 19-13 is reduced to:

$$F_d = \frac{K\,(K_{hd}\%H)}{GCV}$$

Where:

F_d = oxygen-based F-factor on a dry basis (dscf/MMBtu)

K = heat input conversion factor = 10^6 Btu/MMBtu [per Method 19, §12.1]

K_{hd} = hydrogen conversion factor = (3.64 scf/lb)/% [per Method 19, §12.1]

%H = percent hydrogen in the fuel being combusted = 100%

GCV = Gross Calorific Value of hydrogen = 61,021 Btu/lb [GREET Model 2019[3]]

Using the above values, the F_d-factor for hydrogen is calculated as follows:

$$F_d = \frac{1{,}000{,}000\ \text{Btu}}{\text{MMBtu}} * \frac{\frac{3.64\frac{\text{scf}}{\text{lb}}}{\%} * 100\%\text{H}}{61{,}021\,\frac{\text{Btu}}{\text{lb}}} = \mathbf{5,966\ dscf/MMBtu}$$

B. Combined F-factor Development for Hydrogen/Natural Gas Blends

In order to determine the combined F-factor for hydrogen/natural gas blends combusted by a turbine, the proportional ratio (by volume) of each fuel's F-factor is added together, depending upon the % hydrogen blended with natural gas as follows:

$$F_{HNG} = F_H\frac{\%H}{100} + \; F_{NG}\frac{\%NG}{100}$$

[3] Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model. See https://afdc.energy.gov/fuels/properties and https://greet.anl.gov/.

Where:

F_{HNG} = combined F_d-factor for hydrogen/natural gas blends (dscf/MMBtu)

F_H = F_d-factor for hydrogen = 5,966 dscf/MMBtu [per Section A]

F_{NG} = F_d-factor for natural gas = 8,710 dscf/MMBtu [per Method 19, Table 19-2]

%H = percent hydrogen in the fuel being combusted

%NG = percent natural gas in the fuel being combusted

Following is an example for how to determine the combined F-factor for a fuel consisting of a 30% hydrogen/70% natural gas blend:

$$F_{HNG} = 5{,}966\frac{\text{dscf}}{\text{MMBtu}} * \frac{30\%H}{100} + 8{,}710\frac{\text{dscf}}{\text{MMBtu}} * \frac{70\%NG}{100} = \mathbf{7,887\ dscf/MMBtu}$$

Table 1 of this memo summarizes the combined F-factors for hydrogen/natural gas blends at 5% increments, using the above equation.

Table 1. F_d-Factors for Hydrogen/Natural Gas Blends

% Hydrogen	F_{HNG}-Factor (dscf/MMBtu)	% Natural Gas
0	8,710	100
5	8,573	95
10	8,436	90
15	8,298	85
20	8,161	80
25	8,024	75
30	7,887	70
35	7,750	65
40	7,612	60
45	7,475	55
50	7,338	50
55	7,201	45
60	7,064	40
65	6,926	35
70	6,789	30
75	6,652	25
80	6,515	20
85	6,378	15
90	6,240	10
95	6,103	5
100	5,966	0

Table 1 Notes

1. The default natural gas F_d-factor of 8,710 dscf/MMBtu is listed in Method 19, Table 19-2.
2. The default natural gas F_d-factor is based upon a conservative chemical composition (by volume) of 75.5% methane, 14.5% ethane, 1.5% carbon dioxide, and 1.5% nitrogen. Assuming a natural gas content of 100% methane results in a slightly lower F_d-factor of 8,625 dscf/MMBtu.
3. The default F-factors for the various fuels listed in Method 19 are based on the EPA standard conditions of 68 °F and 29.92 in. Hg.
4. An indicator line has been provided in the table to illustrate the "30 percent hydrogen cutoff" between natural gas-fired combustion turbines and non-natural gas-fired combustion turbines, in the proposed NSPS Subpart KKKKa rule.

Note that Table 1 is provided for informational purposes only. When determining the specific combined F-factor for a given hydrogen/natural gas blend, the emission rate should be calculated using the nearest 1% increment of hydrogen and natural gas.

C. Converting NO_x ppm to lb/MMBtu

When emissions measurements are made on a dry basis for both the diluent oxygen and pollutant concentrations, Equation F-5 of 40 CFR Part 75, Appendix F (which is based upon Equation 19-1 of Method 19) is used:

$$E = KC_d F_d \frac{20.9}{(20.9 - \%O_2)}$$

Where:

E = pollutant mass emission rate (lb/MMBtu)

K = NO_x conversion factor = 1.194 x 10^{-7} (lb/dscf)/ppm [per Method 19, Table 19-1]

C_d = NO_x pollutant concentration, dry basis (ppmvd)

F_d = oxygen-based F-factor on a dry basis (dscf/MMBtu)

$\%O_2$ = O_2 diluent concentration, dry basis (%)

Following is an example for how to convert NO_x ppm to lb/MMBtu, for a fuel consisting of a 30% hydrogen/70% natural gas blend, with an emissions concentration of 25 ppmvd NO_x @ 15% O_2:

$$E = 1.194 \text{ x } 10^{-7} \frac{\frac{\text{lb}}{\text{dscf}}}{\text{ppm}} * 25 \text{ ppmvd } NO_x * 7{,}887 \frac{\text{dscf}}{\text{MMBtu}} * \frac{20.9}{(20.9 - 15\%O_2)} = \mathbf{0.083\ lb/MMBtu}$$