Guidelines for the Reduction of Nitrogen Oxide Emissions from Natural Gas–fuelled Stationary Combustion Turbines

Environment and Climate Change Canada

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1. Foreword

The development of the **Guidelines for the Reduction of Nitrogen Oxide Emissions from Natural Gas–fuelled Stationary Combustion Turbines** (henceforth "the Guidelines"), published under section 54 of the *Canadian Environmental Protection Act, 1999* (CEPA), follows the agreement made by federal, provincial and territorial environment ministers to better protect human health and the environment by endorsing and implementing a new Air Quality Management System (AQMS). The AQMS includes Canadian Ambient Air Quality Standards for fine particulate matter and ground-level ozone, Base Level Industrial Emissions Requirements (BLIERs) and local Air Zone Management by the provincial/territorial jurisdictions.

Environment and Climate Change Canada led a multi-stakeholder BLIERs working group that developed consensus-based NO_x emission requirements for new natural gas–fuelled stationary combustion turbines. These requirements form the foundation for the emission limits in the Guidelines.

The Guidelines introduce a NO_x emission limit that is up to 50% more stringent than emission limits set out in the *National Emission Guidelines for Stationary Combustion Turbines* published by the Canadian Council of Ministers of the Environment (CCME) in 1992.

The Minister of the Environment and Climate Change recommends that the appropriate regulatory authorities adopt the Guidelines as a baseline emission limit for NO_x from natural gas–fuelled stationary combustion turbines. However, the Guidelines do not prevent provinces or territories from setting more stringent emission requirements for combustion turbines via their own provincial policies. As well, the Minister of the Environment and Climate Change continues to recommend those requirements of the 1992 CCME Guidelines that have not been superseded by the requirements in this document.

2. Definitions

The following definitions apply in these Guidelines:

"Calendar year" means the period of 12 consecutive months that begins on January 1.

"CFR" means Title 40, Chapter I of the *Code of Federal Regulations* of the United States.

"Cogeneration" means the integrated operation of one or more combustion turbines and steam generators that recover any heat from combustion turbine exhaust gases to supply steam for useful purposes other than electricity generation (e.g., to a heating system or an industrial process).

"Combined cycle" means the integrated operation of one or more combustion turbines and steam turbines for the production of electricity using the same source of thermal energy.

"Combustion turbine" means an engine that operates according to the Brayton thermodynamic cycle, which burns fuel and allows the products of combustion at a high temperature to expand through a rotating power turbine to produce motive power.

"Commissioning date" means the first day on which a combustion turbine begins to produce electricity or motive power.

"Continuous Emissions Monitoring System (CEMS)" means equipment for the sampling, conditioning and analyzing of emissions from a given source and recording of data related to those emissions.

"Emergency combustion turbine" means a combustion turbine that operates only in emergency situations, including to produce power for critical networks or equipment during electric power interruptions, to pump water in the case of fire or flood, or for equipment or facility re-start.

"Natural gas" means a naturally occurring fluid mixture of hydrocarbons (e.g., methane, ethane or propane) produced in geological formations beneath the Earth's surface that maintains a gaseous state at standard atmospheric temperature and pressure under ordinary conditions. Natural gas is composed of at least 85% methane by volume, and it excludes landfill gas, digester gas, refinery gas, sour gas, blast furnace gas, coal-derived gas, producer gas, coke oven gas or any gaseous fuel produced in a process that might result in highly variable sulphur content or heating value.

"New combustion turbine" means a combustion turbine whose commissioning date is on or after 2020 January first.

"Nitrogen oxide (NO_x)" means oxides of nitrogen, which is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2).

"Operator" means a person who has the charge, management or control of a combustion turbine.

"Part-load operation" means the operation of the combustion turbine below 70% of its power rating.

"Peaking combustion turbine" means a combustion turbine that is operated for 1500 hours or less within a calendar year.

"Predictive Emission Monitoring System (PEMS)" means all of the equipment and related activities required to determine an emission concentration or an emission rate. This may include processor control devices, sensors, operating parameter measurements, conversion equations, graphs or computer programs to produce results in units of the applicable emission limit or standard.

"Power rating" means normal maximum continuous rating (in megawatts – MW) at International Organization for Standardization (ISO) 3977-2 environmental design point conditions of ambient air: 15°C (288K), 60% relative humidity and 101.3 kilopascals barometric pressure.

"Shut-down period" means the period of time between the moment when the combustion turbine is operating at normal operating mode and the moment when it is non-operational.

"Simple cycle combustion turbine" means a combustion turbine that operates without harnessing the turbine exhaust heat for useful purposes.

"Start-up period" means the period of time between the moment when the combustion turbine is non-operational and the moment when it is operating at normal operating mode.

3. Scope

3.1. Subject to section 3.2 and 3.3, these Guidelines set NO_x emission limits for new combustion turbines with a power rating equal to or greater than 1 MW.

3.2. These Guidelines do not apply to the following:

- emergency combustion turbines;
- combustion turbines used solely for purposes of research and development and field demonstration; and
- combustion turbines under repair, those being tested during their commissioning period or during verification of repairs.

3.3. Section 4 of these Guidelines does not apply to peaking combustion turbines with a power rating of less than 4 MW. However, the other sections of these Guidelines should still be met.

4. NO_x Emission Limits

4.1. The performance of the combustion turbines should be determined using either one of the following methods:

i. the output-based method; or
ii. the concentration-based method.

4.2. The NO_x emission limits in tables 1 and 2 are a function of the turbine application and its power rating (expressed in MW). These limits do not apply during start-up periods, shut-down periods, periods of part-load operation or when the ambient temperature at the point of air intake is less than -18°C.

4.3. Output-based method

Under the output-based method, limits are expressed as emission intensity (mass of NO_x per unit output of shaft or electrical energy). To conform with these Guidelines, an operator should meet the applicable emission limit mentioned in Table 1. The NO_x emission limits take into consideration the quantity of energy produced by the combustion turbine, calculated in gigajoules (GJ), as well as the emissions, calculated in grams (g) of NO_x.

Table 1: Natural gas combustion turbines NO_x emission limits – output-based method

Application	Turbine power rating (MW)	NO_x emission limits ($g/GJ_{(energy\ output)}$)
Non-peaking combustion turbines – mechanical drive	≥ 1 and < 4	500
Non-peaking combustion turbines – electricity generation	≥ 1 and < 4	290
Peaking combustion turbines – all*	≥ 1 and < 4	exempt
Non-peaking combustion turbines and peaking combustion turbines – all*	≥ 4 and ≤ 70	140
Non-peaking combustion turbines – all*	> 70	85
Peaking combustion turbines – all*	> 70	140

* The term “all” refers to combustion turbines used for either mechanical drive or electricity generation

4.4. Concentration-based method

Under the concentration-based method, emission limits are expressed as a concentration of NO_x. If this method is chosen, the concentration of NO_x at the combustion turbine exhaust should not exceed the limit set out in Table 2. The concentation-based method should not be used for combustion turbines operated in cogeneration configuration.

Table 2: Natural gas combustion turbines NO_x emission limits – concentration-based method

Application	Turbine power rating (MW)	NO_x emission limits (ppm_v*) @ 15% O_2
Non-peaking combustion turbines – mechanical drive	$\geq$ 1 and < 4	75
Non-peaking combustion turbines – electricity generation	$\geq$ 1 and < 4	42
Peaking combustion turbines – all**	$\geq$ 1 and < 4	exempt
Non-peaking combustion turbines and peaking combustion turbines – all**	$\geq$ 4 and ≤ 70	25
Non-peaking combustion turbines – all**	> 70	15
Peaking combustion turbines – all**	> 70	25

* parts per million by volume (ppm_v)
** The term “all” refers to combustion turbines used for either mechanical drive or electricity generation

5. Testing and Monitoring

5.1. The combustion turbine should be operated and maintained in accordance with the specifications set out by its manufacturer or required by its design.

5.2. An initial emission performance test should be conducted within six months of the combustion turbine’s commissioning date to demonstrate compliance with the NO_x emission limits, in accordance with the requirements in Appendix 1.

5.3. To verify compliance with the NO_x emission limits, an emission performance test should be conducted or the emission concentration should be monitored following the requirements in Appendix 1 and as follows:

i. For a non-peaking combustion turbine used to generate electricity with a power rating greater than 25 MW, a Continuous Emissions Monitoring System (CEMS) should be operated;

ii. For any other combustion turbine with a power rating greater than 25 MW, a NO_x emission performance test should be conducted once per calendar year;

iii. For a combustion turbine with a power rating less than or equal to 25 MW, a NO_x emission performance test should be conducted once every three calendar years.

5.4. Emission performance testing should not be conducted during start-up periods, shut-down periods, periods of malfunction, periods of part-load operation or when the ambient temperature at the point of air intake is less than -18°C.

Appendix 1: Quantification Protocol

A. Compliance Determination: Testing Methods

1. Compliance of a new combustion turbine with these Guidelines should be determined using either of the following methods:
   a. the output-based method (expressed as gNO_x/GJ); or
   b. the concentration-based method (ppm_v NO_x) at 15% O_2, on a dry basis.

Output-based Method

2. For a combustion turbine to meet the applicable emission limit set out in Table 1, at the operating conditions stated in Part D, the operator should conform with the following principles to calculate NO_x emission rates:
   a. Measure concurrently the following:

      i) the stack gas flow in accordance with the U.S. Environmental Protection Agency (EPA) method entitled *Method 2 – Determination of Stack Gas Velocity and Volumetric Flow Rate (Type S pitot tube)* set out in Appendix A-1 to part 60 of the CFR or the method published by Environment and Climate Change Canada known as *Method B: Determination of Stack Gas Velocity and Volumetric Flow Rate* (EPS 1/RM/8), and

      ii) the NO_x concentration in accordance with the EPA method entitled *Method 7E – Determination of Nitrogen Oxides Emissions from Stationary Sources (Instrumental Analyzer Procedure),* set out in Appendix A-4 to Part 60 of the CFR, to determine the NO_x emission rate during three contiguous thirty-minute periods.

   b. Non-ideal stack gas flow conditions may require the application of EPA method entitled *Method 2G – Determination of Stack Gas Velocity and Volumetric Flow Rate with Two-dimensional Probes*, set out in Appendix A-2 to part 60 of the CFR or EPA method entitled Method 2F – *Determination of Stack Gas Velocity and Volumetric*

Flow Rate with Three-dimensional Probes, set out in Appendix A-1 to part 60 of the CFR.

c. Calculate the NO_x emission rate using Equation (1) below:

$$E_{NO_x} = C_{meas'd} \times 1.88 \times 10^{-3} \times Q_s \qquad (1)$$

where:

E_{NO_x} is the NO_x emission rate expressed as g NO_x/h

$C_{meas'd}$ is the NO_x concentration, in ppm_v, on a dry basis

1.88×10^{-3} is the conversion factor for NO_x from ppm_v to g/m^3

Q_s is the stack gas flow rate, in m^3/hr, on a dry basis and in reference conditions of 25°C and 101.325 kPa

d. Alternately, determine the NO_x emission rate by measuring the heat (fuel) input and NO_x and O_2 concentration in accordance with the EPA method entitled Method 20 – *Determination of Nitrogen Oxides, Sulfur Dioxide, and Diluent Emissions from Stationary Gas Turbines*, set out in Appendix A-7 to part 60 of the CFR, during three contiguous thirty-minute periods. The NO_x emission rate is calculated using Equation (2) below:

$$E_{NOx} = C_{meas'd} \times F_d \times HI \times 1.88 \times 10^{-3} \times \frac{20.9}{(20.9 - \%O_2)} \qquad (2)$$

where:

E_{NO_x} is the NO_x emission rate expressed as g NO_x/h

$C_{meas'd}$ is the NO_x concentration, in ppm_v, on a dry basis

F_d is the F-factor for natural gas on a dry basis, 240 DSm^3/GJ, mentioned in Appendix A, Table A-1 of the method published by Environment and Climate Change Canada entitled *Protocols and Performance Specifications for Continuous Monitoring of Gaseous Emissions from Thermal Power Generation* (EPS 1/PG/7)

1.88×10^{-3} is the conversion factor for NO_x from ppm_v to g/m^3

HI is the gross heat input to the turbine system (natural gas), in GJ/h

$\%O_2$ is the measured O_2 concentration, in % (v/v), on a dry basis

e. Verify compliance of the combustion turbine not operating in a cogeneration application with the applicable output-based limit according to the Equation (3) below:

$$A \geq \frac{E_{NOx}}{PO} \qquad (3)$$

where:

A is the applicable output-based emission limit in Table 1, in g/GJ

E_{NO_x} is the NO_x emission rate, in g NO_x/h, calculated using equations (1) or (2)

PO[1] is the power output, the combined electricity and shaft power produced by the combustion turbine and the steam turbine(s) during an emission testing period, in GJ/h

f. In the case of a combustion turbine operating in a cogeneration application, verify compliance with the applicable output-based limit by calculating the NO_x emission rate according to Equation (4) below:

$$E_{NOx} \leq (PO \times \mathrm{A}) + (HO \times 40) \qquad (4)$$

where:

E_{NOx} is the NO_x emission rate, in g NO_x/h, as calculated using equations (1) or (2)

[1] In configurations with multiple combustion turbines and/or multiple steam turbines, the power output of each steam turbine(s) should be proportionally allocated to the power output of each combustion turbine, according to its contribution to the input energy of each steam turbine.

PO[1] is the power output, the combined electricity and shaft power, produced by the combustion turbine and the steam turbine(s) during an emission testing period, in GJ/h

A is the applicable output-based emission limit in Table 1, in g/GJ

HO[2] is the heat output produced by the combustion turbine (in a simple cycle configuration) or the steam turbine(s) (in a combined cycle configuration) operating in cogeneration application during an emission testing period, in GJ/h

40 is the Cogeneration Coefficient, in g/GJ

Concentration-based Method

3. For a combustion turbine to meet the concentration-based emission limits set out in Table 2 at the operating conditions outlined in Part D, the operator should conform with the following principles:

   a. Measure concurrently the O_2 and NO_x concentrations in accordance with the EPA method entitled *Method 20 – Determination of Nitrogen Oxides, Sulfur Dioxide, and Diluent Emissions from Stationary Gas Turbines*, set out in Appendix A-7 to part 60 of the CFR, during three contiguous thirty-minute periods.

   b. Correct each measured NO_x value to a concentration at 15% oxygen using Equation (5) below:

$$C_{NOx,15\%} = C_{meas'd} \times \frac{(20.9-15)}{(20.9-\%O_2)} \qquad (5)$$

where:

$C_{NOx,15\%}$ is the concentration of NO_x corrected to 15% O_2, in ppm_v, on a dry basis

$C_{meas'd}$ is the measured NO_x concentration, in ppm_v, on a dry basis

$\%O_2$ is the measured O_2 concentration, in % (v/v), on a dry basis

[2] In configurations with multiple combustion turbines and/or multiple steam turbines, the heat output (HO) of each steam turbine should be proportionally allocated to each combustion turbine according to its contribution to the input energy of each steam turbine.

c. Calculate the final NO_x concentration in ppm_v at 15% $O_{2,}$ on a dry basis by averaging the value for each thirty-minute period.

d. Verify compliance of the combustion turbine with the applicable concentration-based emission limit according to Equation (6) below:

$$A \geq C_{NOx,15\%} \qquad (6)$$

where:

A is the concentration-based emission limit in Table 2, in ppm_v

$C_{NOx,15\%}$ is the concentration of NO_x corrected to 15% O_2, in ppm_v, on a dry basis calculated using equation (5)

B. Quantification of Production

1. The operator of the combustion turbine should install, maintain and operate a device to measure the mechanical output and, as the case may be, the gross electrical output of the combustion turbine during NO_x testing. The combined values from these devices should give the power (mechanical and/or electric) output of the unit.

2. The operator of the combustion turbine should install,maintain and operate a device to measure the heat output delivered by the combustion turbine operating in a cogeneration application during NO_x testing.

C. Compliance Determination: Continuous Emissions Monitoring System

1. A Continuous Emissions Monitoring System (CEMS) may be used to measure NO_x emissions in lieu of stack testing.

2. A CEMS should be used on non-peaking electricity generating combustion turbines with a power rating greater than 25 MW.

3. The CEMS should meet the specifications for design, installation, certification and quality assurance/quality control (QA/QC) set out in the method published by Environment and Climate Change Canada entitled *Protocols and Performance Specifications for Continuous Monitoring of Gaseous Emissions from Thermal Power Generation* (EPS 1/PG/7) or the method published by Alberta Environmental Protection entitled *Continuous Emission Monitoring System (CEMS) Code*.

4. As an alternative, a Predictive Emission Monitoring System (PEMS) is an acceptable equivalent to a CEMS if it meets the EPA method entitled *Method 16 – Specifications and Test Procedures for Predictive Emission Monitoring Systems in Stationary Sources*, set out in the Title 40, Chapter I, Subchapter C, part 60, of the CFR.

5. NO_x emissions information (e.g., data averages) should be collected for the purpose of these Guidelines when the turbine operates at the conditions outlined in Part D.

6. For the output-based method, the operator should also, during the period of data collection:

    a. Install, maintain and operate a device to measure heat input so that NO_x emissions information can be converted to mass per hour emission rate using equation B-1 in Appendix B of the method published by Environment and Climate Change Canada entitled *Protocols and Performance Specifications for Continuous Monitoring of Gaseous Emissions from Thermal Power Generation* (EPS 1/PG/7). An average rate should be determined.
    b. Install,maintain and operate a device to continuously measure the mechanical and, as the case may be, the gross electrical output of the unit; determine the combined mechanical and electric output of the unit; calculate the average hourly output.
    c. Measure the heat output delivered from the combustion turbine operating in a cogeneration application during an emissions testing period; calculate the average hourly output.
    d. Verify compliance with the applicable output-based limit by calculating the emission rate using equations (3) and (4) in Part A.

D. Operating Conditions

1. The measurement of NO_x emissions should be done under normal operating conditions as follows:

    a. All emission performance tests should be conducted when the combustion turbines is operated at a load level that is within 70% to 100% of its power rating.
    b. Despite paragraph (a), testing may be conducted at the highest achievable load, if it is not practically possible to operate the combustion turbine at a load equal to or greater than 70% of its power rating.
    c. Testing should reflect typical operation conditions and fuel characteristics. Testing under atypical or artificial conditions will not satisfy the requirements of these guidelines.

d. Testing should be done at ambient temperatures greater than or equal to -18°C.

2. When more than one combustion turbine is venting through a common stack, the emission samples taken from that stack should take place with one combustion turbine operating at a time.

   However, if more than one combustion turbine shares air emission control equipment, one emission sample can be taken for all turbines when taken downstream of the air emission control equipment.

E. Accuracy of Data

1. Measurement devices required for these Guidelines should be calibrated at the most frequent of the following:

   a. at least once every three calendar years;
   b. at the frequency recommended by the manufacturer; or
   c. as specified in the test methods for the devices.

2. Each measurement device should enable measurements to be made within an accuracy of ± 5%.