Guidance Document for Cogeneration Emissions

(Cogeneration Guidelines)

October 2008

Alberta Environment

Introduction

This document replaces the "Guidance Document for Cogeneration Emissions" (2006).

The Emissions Trading Regulation (Alberta Regulation 33/ 2006) is called the *Regulation* in this document. If this document contradicts the Regulation, the Regulation is paramount.

This document is referred in the Regulation as the "Cogeneration Guidelines" or the "Guidance Document for Cogeneration Emissions".
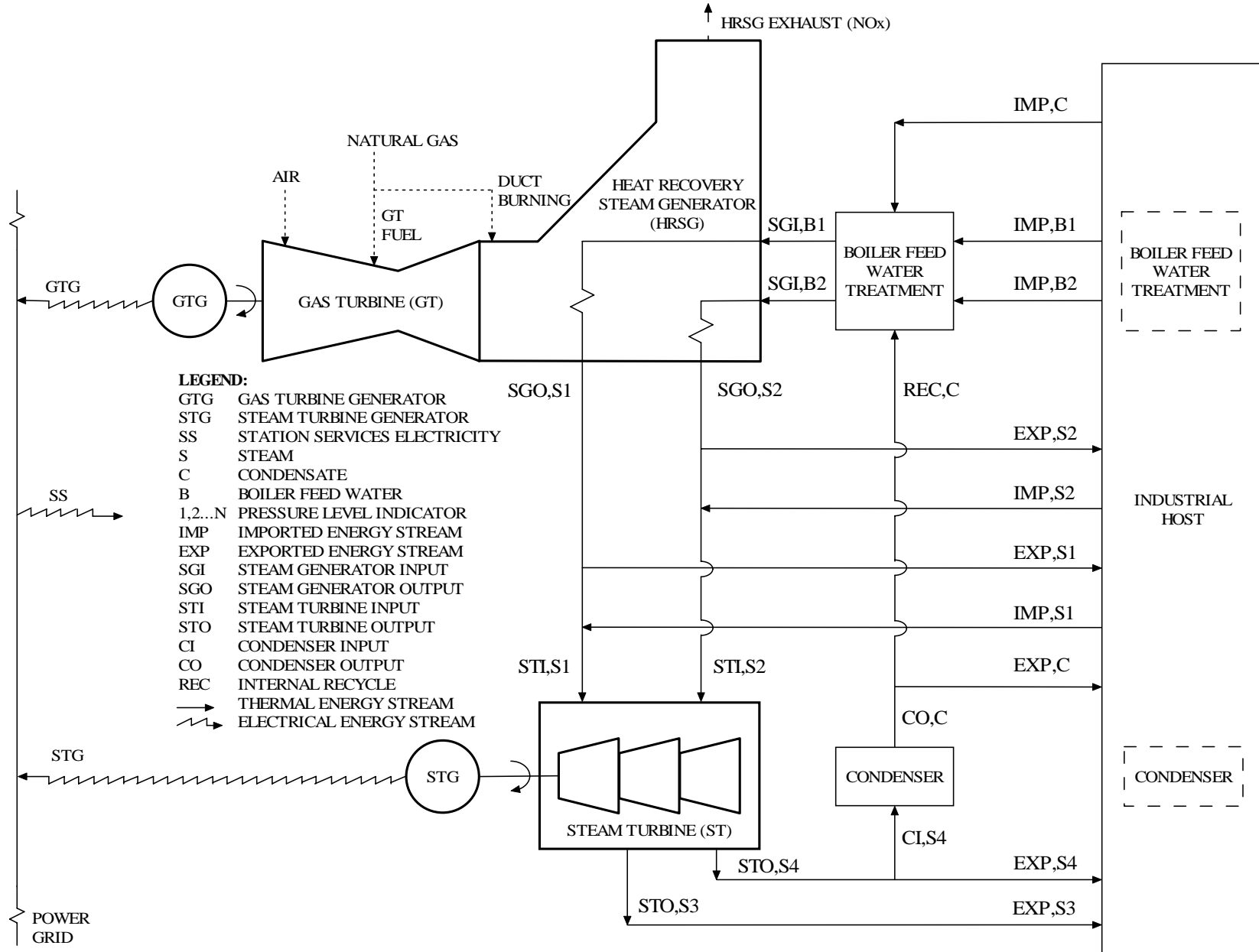
The following document is an elaboration on Appendix A of the Air Emission Standard For Electricity Generators (2005).

Cheminfo Services Ltd. (Toronto) provided technical expertise for this document. Alberta Environment is responsible for this document.

Cogeneration Flow Diagram

Figure 1 *Generic Cogeneration Unit Process Flow Diagram* shows electric and thermal power transmissions for a cogeneration unit. Most units are simpler than what is represented in Figure 1. Nomenclature in Figure 1 one is used to describe thermal flows in the following equations.

Figure 1: Generic Cogeneration Unit Process Flow Diagram

LEGEND:

GTG	GAS TURBINE GENERATOR
STG	STEAM TURBINE GENERATOR
SS	STATION SERVICES ELECTRICITY
S	STEAM
C	CONDENSATE
B	BOILER FEED WATER
1,2...N	PRESSURE LEVEL INDICATOR
IMP	IMPORTED ENERGY STREAM
EXP	EXPORTED ENERGY STREAM
SGI	STEAM GENERATOR INPUT
SGO	STEAM GENERATOR OUTPUT
STI	STEAM TURBINE INPUT
STO	STEAM TURBINE OUTPUT
CI	CONDENSER INPUT
CO	CONDENSER OUTPUT
REC	INTERNAL RECYCLE
→	THERMAL ENERGY STREAM
⟿	ELECTRICAL ENERGY STREAM

1. Nitrogen Oxides Emission Intensity

1.1 Nitrogen Oxides Emission Intensity

The nitrogen oxides emission intensity for a cogeneration unit is the unit's nitrogen oxide emissions (NO_x) expressed as NO_2 over a defined period divided by the net usable thermal and electric power from the unit over the same defined period.

The defined period for Section 55 of the Regulation is a calendar year. The defined period for the baseline emission rate is specified in the Section 21 of the Regulation. The net usable energy output includes the net usable electricity output and the net usable thermal energy output from the unit.

$$\text{Nitrogen oxides emission intensity} = \frac{\text{NOx Emissions (over defined period)}}{\text{Total Net Usable Energy Output (over defined period)}}$$

$$I \quad = \frac{N}{P} \quad = \frac{N}{(E+H)} \qquad \qquad \text{Equation 1}$$

where:

I	= NOx Emissions Intensity (kg/MWh);
N	= NOx Emissions (expressed as kg of NO_2);
P	= Net Usable Energy Output (MWh);
E	= Net Usable Electrical Energy Output (MWh);
H	= Net Usable Thermal Energy Output (MWh);

Intensities for the Regulation are calculated as the mass of emissions over net energy output. The average of intensities in different periods is not used.

1.1.1 NOx Emissions

NOx emissions are reported on an NO_2 basis in kilograms.

1.1.2 Net Usable Electrical Energy Output

Net usable electrical energy output is the usable outflow of electrical energy across the boundary of the cogeneration unit.

Electrical energy used internally by the cogeneration system for station services (e.g. auxiliary power, start-up, control systems, etc.) is excluded from the total.

If the cogeneration unit draws electrical energy for station services from a source on the AESO grid, this imported electrical energy is deducted from the unit's total electrical energy output.

Net Usable Electrical Energy Output = Gross Electrical Energy Outputs - Electrical Energy for Station Services

$$E = G - SS \qquad \text{Equation 2}$$

where:

E = Net Usable Electrical Energy Output (MWh);
G = Gross Electrical Energy Output (MWh);
SS = Electrical Energy for Station Services (MWh);

1.1.3 Net Usable Thermal Energy Output

The net usable thermal energy output is the second of the two energy terms in the denominator of the intensity calculation. It is the net usable outflow of thermal energy across the boundary of the cogeneration unit. It is calculated as the total usable thermal energy exported from the unit less the total usable thermal energy imported to the unit over the defined time period.

Net Usable Thermal Energy Output = Sum of Usable Thermal Energy Stream Exports
- Sum of Usable Thermal Energy Stream Imports

$$H = \sum_{X=1}^{M} H_{EXP,X} - \sum_{X=1}^{N} H_{IMP,X} \qquad \text{Equation 3}$$

where:

H = Net Usable Thermal Energy Output (MWh);
$H_{EXP,X}$ = Thermal Energy of Usable Exported Stream X (MWh);
$H_{IMP,X}$ = Thermal Energy of Usable Imported Stream X (MWh);
X = Identifier of any Usable Thermal Energy Stream;
M = Number of Exported Usable Thermal Energy Streams;
N = Number of Imported Usable Thermal Energy Streams;

It is important to note that the net usable thermal energy output calculation does not depend on internal energy streams flowing within the cogeneration unit. For example, the steam flow from the heat recovery steam generation unit to the steam turbine or the condensate returned (within the unit boundary) to the heat recovery steam generation unit are not part of the calculation. Only thermal energy streams that flow across the boundary of the cogeneration unit are considered in the NOx emission intensity calculation.

Using stream identifiers as suggested by Figure 1, the equation for net usable thermal energy output can be expanded to as many export and import thermal energy streams that exist within a cogeneration system.

$$H = H_{EXP,S1} + H_{EXP,S2} + H_{EXP,S3} + H_{EXP,C} + \ldots + H_{EXP,X}$$
$$- H_{IMP,S1} - H_{IMP,S2} - H_{IMP,S3} - H_{IMP,B1} - H_{IMP,B2} - H_{IMP,C} - \ldots - H_{IMP,X} \qquad \text{Equation 4}$$

where:

H = Net Usable Thermal Energy Output (MWh);
$H_{EXP,S1}$ = Thermal Energy of Exported High-Pressure Steam (MWh);
$H_{EXP,S2}$ = Thermal Energy of Exported Medium-Pressure Steam (MWh);
$H_{EXP,S3}$ = Thermal Energy of Exported Low-Pressure Steam (MWh);
$H_{EXP,C}$ = Thermal Energy of Exported Condensate (MWh);
$H_{EXP,X}$ = Thermal Energy of Other Usable Exported Stream X (MWh);
$H_{IMP,S1}$ = Thermal Energy of Imported High-Pressure Steam (MWh);
$H_{IMP,S2}$ = Thermal Energy of Imported Medium-Pressure Steam (MWh);
$H_{IMP,S3}$ = Thermal Energy of Imported Low-Pressure Steam (MWh);
$H_{IMP,B1}$ = Thermal Energy of Imported High-Pressure Boiler Feed Water (MWh);
$H_{IMP,B2}$ = Thermal Energy of Imported Medium-Pressure Boiler Feed Water (MWh);
$H_{IMP,C}$ = Thermal Energy of Imported Condensate (MWh);
$H_{IMP,X}$ = Thermal Energy of Other Usable Imported Stream X (MWh);
X = Identifier of any Usable Thermal Energy Stream; and

Some cogeneration units use heat transfer fluids other than water and steam. These fluids include glycol-based substances. Equation 4 can be used for these fluids.

1.1.4 Non-Usable Thermal Energy Streams

Non-usable thermal energy streams should not be included in the calculation of net usable thermal energy output. These streams should be omitted if they do not provide any useful energy to the industrial host. These streams include boiler blowdown and condenser cooling water.

2. NOx Emission Credits

2.1 Credit Generation

NOx emission reduction credits are generated when a cogeneration unit operates at a NO_x emissions intensity that is lower than its NO_x baseline emission rate or credit generation threshold.

2.1.1 Credit Generation Equation

The generation of NO_x emission reduction credits is based on the net annual electrical energy output. All electricity energy output is used in the calculation except that used for station services.

Annual NO_x Emission Reduction Credits
= Annual Net Electrical Energy Output × (NO_x Baseline Emission Rate - Annual NO_x Emission Intensity)

$$C = E \times (BER - AI) \hspace{4cm} \text{Equation 5}$$

where:

C = Annual NO_x Emission Reduction Credits Generated in Year X (tonnes);
E = Annual Net Usable Electrical Energy Output (MWh);
BER = Baseline Emission Rate (or Credit Generation Threshold) (kg/MWh);
AI = Annual NO_x Emission Intensity (kg/MWh).

Appendix A: Acronyms, Variables, and Terms

Table 1: Typical Properties of HRSG Steam and Water Streams

Thermal Energy Stream	Pressure Range		Temperature Range*	Enthalpy Range
	(bar)	(psi)	(°C)	(kJ/kg)
High pressure steam	20-50	300-750	250-450	2,900-3,400
Medium pressure steam	7-20	100-300	200-300	2,800-3,100
Low pressure steam	3-7	50-100	150-250	2,700-3,000
Boiler feed water	variable	variable	50-150	200-700
Condensate**	3-7	50-100	25-100	100-400

* upper end depends on degree of superheating;   ** typically condensed from low-pressure steam

Table 2: Equipment Identifiers

Acronym	Description	Comments
GT	Gas Turbine	rotary gas combustion engine with turbine blades powered by combustion gases
GTG	Gas Turbine Generator	generator of electricity from gas turbine shaft energy
HRSG	Heat Recovery Steam Generator	heat recovery boiler that generates steam from boiler feed water based on heat from gas turbine combustion gases and duct firing; also can superheat existing steam streams
ST	Steam Turbine	rotary turbine powered by one or more pressure levels of steam
STG	Steam Turbine Generator	generator of electricity from steam turbine shaft energy
C	Condenser Unit	unit that condenses low-pressure steam into clean condensate
AESO	Alberta Electricity System Operator	AESO Grid is the Alberta public power grid

Table 3: Units For Variables

Notation In Guide	Variable Description	Units	Comments
P	Energy (MWh)	MWh	Energy in any form, electrical or thermal, depending on subscript
None	Mass	Tonnes	mass of fluid that has flowed in a time period
None	Unit Enthalpy	kJ/kg	enthalpy of one mass unit of fluid; enthalpy for water or steam obtained from steam tables
None	Temperature	°C	temperature of water or steam stream
None	Pressure	kPa, bar	pressure of water or steam stream; usually measured as "gauge" pressure; conversion to "absolute" pressure required for steam tables
None	Conversion Factor	MWh/kJ	U (2.778 x 10^{-7} MWh/kJ) is a unit conversion factor required to convert energy from kJ units to MWh units; (same result is achieved by dividing by 3.6 x 10^6 kJ/MWh)
None	Heat Capacity	kJ/kg-°C	capacity of fluid to hold energy; similar to enthalpy but requires temperature; used only for heat-transfer fluids
None	Annual Emission Intensity Period	Hours	duration of time period for calculation of annual NOx emission intensity (usually one year or 8,760 hours)
None	Baseline Time Period	hours	duration of time period for NOx baseline emission rate (usually 3 years or 26,280 hours)
E	Electrical Energy	MWh	Net electrical energy output.
H	Thermal Energy	MWh	Net thermal energy output. Gigajoules converted to megawatt hours.
N	NO$_x$ Emissions	Kg	Oxides of Nitrogen expressed as NO$_2$
G	Gross Electrical Energy	MWh	Gross electrical energy output from the turbines.
SS	Station services	MWh	All own use power by the cogeneration facility whether for running the facility or generating the electricity.

Table 4: Variable Subscripts

Subscript	Description	Comment
GTG	Gas Turbine Generation	energy production from Gas Turbine Generator
STG	Steam Turbine Generation	energy production from Steam Turbine Generator
SS	Station Services	internal energy requirement for operation of unit
S	Steam	any pressure level of steam
C	Condensate	any condensed steam stream
B	Boiler Feed Water	water treated to remove solids and dissolved oxygen
1	High-pressure Level	identifier of steam or boiler feed water pressure level
2	Medium-pressure Level	identifier of steam or boiler feed water pressure level
3	Low-pressure Level	identifier of steam or boiler feed water pressure level
IMP	Imported thermal energy stream; or total imports	identifier of a stream that flows across the unit boundary into a cogeneration unit
EXP	Exported thermal energy stream	identifier of a stream that flows across the unit boundary out of cogeneration unit
SGI	Steam Generator Input	identifier of a stream that flows into the Steam Generator (HRSG)
SGO	Steam Generator Output	identifier of a stream that flows out of the Steam Generator (HRSG)
STI	Steam Turbine Input	identifier of a steam stream that flows into the Steam Turbine (ST)
STO	Steam Turbine Output	identifier of a steam stream that flows out of the Steam Turbine (ST)
CI	Condenser Input	identifier of a stream that flows into the Condenser unit
CO	Condenser Output	identifier of a stream that flows out of the Condenser unit
REC	Internal Recycle Stream	identifier of a stream that is recycled within the unit
X	Thermal Energy Stream	any thermal energy stream
GC	Gas Combustion	refers to energy derived internally from on-site gas combustion
Avg	Average	average value over time period
Gauge	Gauge Pressure	pressure as measured by pressure gauge (where 1 atmosphere = 0)

Absolute	Absolute Pressure	absolute pressure of stream = gauge pressure + 1 atmosphere

Table 5: Common Unit Conversions

Energy	1 kJ	=	2.778×10^{-7} MWh
	1 MWh	=	3.6×10^6 kJ
	1 Btu	=	1.054 kJ
	1 Btu	=	2.93×10^{-7} MWh
	1GWh	=	1000 MWh
Mass	1 tonne	=	1000 kg
	1 kilogram	=	2.2046 pounds
Temperature	T(°C)	=	[T(°F) - 32] ÷ 1.8
Pressure	1 standard atmosphere	=	101.335 kPa
	1 standard atmosphere	=	14.696 pounds per square inch (psi)
	1 psi	=	6.895 kPa
	1 bar	=	100 kPa
Enthalpy	1 Btu/lb	=	2.324 kJ/kg

Table 6: Glossary of Terms

Term	Description
Cogeneration	The simultaneous production of electrical energy and thermal energy
Simple Cycle	Electrical energy production using a gas turbine only; a heat recovery steam generation unit may or may not be used but there is no steam turbine in a simple cycle system
Combined Cycle	Electrical energy production using a gas turbine and a steam turbine
Embedded Unit	Combined cycle cogeneration unit that receives thermal energy for its steam turbine directly from an industrial host. The thermal energy does not pass through the hear recovery steam generation unit.
Baseline Emission Rate	Initial NOx emission intensity for unit calculated over baseline period
Baseline Period	Defined time period of normal unit operation for existing cogeneration units; (usually a 3-year period from 2000-2002 inclusive; can be other time period). Refer to the regulation for an exact definition.
NOx Emission Intensity	NOx emissions per unit of net energy output
Station Services	Internal electrical energy required by unit for normal operation