New Jersey Department of Environmental Protection
Division of Air Quality, Bureau of Stationary Sources

State of the Art (SOTA) Manual for Stationary Combustion Turbines

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Section 3.14 - State of the Art (SOTA)
Manual for Stationary Combustion Turbines

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3.14 SOTA MANUAL FOR STATIONARY COMBUSTION TURBINES

3.14.0 Definitions

"Air-to-Fuel Ratio (A/F)" means the ratio of air to fuel for combustion.

1. An A/F ratio of 1.0 indicates an equal stoichiometric ratio of air (A) to fuel (F).
2. An A/F ratio greater than 1.0 indicates fuel-lean (excess air) or lean burn combustion, with some of the fuel unable to be fully oxidized (combusted).
3. An A/F ratio less than 1.0 indicates fuel-rich (excess fuel) or rich burn combustion, with the fuel able to be fully oxidized (combusted).

"Biogas" means a gas produced by anaerobic digestion or fermentation of organic matter, including landfill gas and digester gas.

"Diesel Fuel" means any fuel sold and suitable for use in diesel engines, and that is one of the following:

1. A distillate fuel commonly or commercially known or sold as No. 1 diesel fuel or No. 2 diesel fuel;
2. A non-distillate fuel other than residual fuel with comparable physical and chemical properties (e.g., biodiesel fuel); or
3. A mixture of either of these types of fuels.

"Diffusion" means fuel and compressed air are separated until the combustion chamber. Fuel combustion occurs at the flame surface, and the interior of the flame contains unburnt fuel.

"Duct Burner" means a device that combusts fuel and that is placed in the exhaust duct of a stationary combustion turbine. A duct burner provides additional heat to turbine exhaust gases, allowing the exhaust gases to generate steam via a heat recovery steam generator.

"Gaseous Fuel" means a material comprised mostly of hydrocarbons in the gaseous state that is combusted to produce heat, including natural gas, propane, biogas, and process gas.

"Higher Heating Value (HHV)" means the heat content of a fuel in units of energy per mass or volume.

"Liquid Fuel" means a material comprised mostly of hydrocarbons in the liquid state that is combusted to produce heat, including diesel fuel, fuel oils, aviation kerosene, and distillate oils.

"Heat Recovery Steam Generator (HRSG)" means a unit that extracts heat from stationary combustion turbine exhaust gases to generate steam. The steam can be used to power a steam turbine or be provided to other devices. HRSG can be used with or without duct burners.

"International Organization for Standardization (ISO) standard dry conditions" means 288 degrees Kelvin (58.7 ºF), 60% relative humidity, and 101.3 kilopascals (14.70 pounds per square inch) pressure.

"Natural Gas" means a fluid mixture of hydrocarbons (e.g., methane, ethane, or propane), composed of at least 70 percent methane by volume or that has a gross calorific value between 35 and 41 megajoules (MJ) per dry standard cubic meter (950 and 1,100 Btu per dry standard cubic foot), that maintains a gaseous State under ISO conditions. In addition, natural gas contains 20.0 grains or less of total sulfur per 100 standard cubic feet. Finally, natural gas does not include the following gaseous fuels: 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 which might result in highly variable sulfur content or heating value.

"Premix" means compressed air and fuel are mixed before combustion. Premixing is used to generate lean combustion (A/F ratio greater than 1.0).

"Seconds, Saybolt Universal (SSU)" is a measure of viscosity determined using a standardized test, specified in ASTM D2161. Viscosity is measured as the time (seconds) taken for 60 milliliters of a liquid to flow through a calibrated tube at 100 ºF.

"Steady state" means all operations except for startup, shutdown, and fuel type switching.

"Stationary Combustion Turbine" means a device in which the combustion of compressed air and a liquid or gaseous fuel generates rotary motion.

3.14.1 Scope

This State-of-the-Art (SOTA) manual establishes emissions performance levels and control technologies for the best performing sources within the U.S. Conformance to the requirements established in this manual by a permit applicant alleviates the need for the applicant to review and establish a case-by-case SOTA for any air contaminant source included in this manual.

These SOTA performance levels apply to stationary combustion turbines with a maximum heat input capacity of 10 million British thermal units (MMBtu) per hour or more, based on the higher heating value (HHV) of the fuel combusted. Turbines equipped with duct burners or heat recovery steam generating units are addressed within this SOTA Manual.

The SOTA thresholds for source operations, which must obtain a Preconstruction Permit pursuant to N.J.A.C. 7:27-8, can be found in:

1. N.J.A.C. 7:27-8, Appendix 1, Table A for criteria pollutants; and
2. N.J.A.C. 7:27-17.9, Tables 3A and 3B for hazardous air pollutants (HAP) and toxic substances (TXS) regulated by the New Jersey Department of Environmental Protection (the Department).

The SOTA thresholds for source operations which must obtain an Operating Permit, pursuant to N.J.A.C. 7:27-22 can be found in:

1. N.J.A.C. 7:27-22, Appendix, Table A; and
2. N.J.A.C. 7:27-17.9, Tables 3A and 3B for HAP and TXS.

If a source operation was omitted in this manual or a stationary turbine combusts a fuel not included in this manual, the applicant must represent SOTA technology using a case-by-case approach, if applicable, pursuant to N.J.A.C. 7:27-8.12 and N.J.A.C. 7:27-22.35. For air contaminants that may be emitted from the sources described in this manual, but for which a performance level is not specified, SOTA will be done on a case-by-case basis pursuant to N.J.A.C. 7:27-8 and N.J.A.C. 7:27-22.

This SOTA Manual includes SOTA standards from the combustion of gaseous or liquid fuels. Additional SOTA standards for the combustion of landfill gas can be found in the SOTA Manual for Equipment Used to Vent Municipal Solid Waste Landfills - Section 3.18.

3.14.1.1 Types of Stationary Combustion Turbines

A combustion turbine is an internal combustion engine that operates with rotary motion. Hot gases are directed through one or more fan-like turbine wheels to generate motive power. The hot exhaust gases may be used to generate additional heat or steam by using heat exchangers, duct burners, heat recovery steam generators (HRSG), or other devices. A turbine is composed of three sections:

1. Compressor: The compressor draws in ambient air and compresses it to approximately 30 times ambient pressure.
2. Combustor: Compressed air and a liquid or gaseous fuel are combined, ignited, and combusted.
3. Turbine: Hot gases are diluted with additional cool air from the compressor section to achieve temperatures up to 2,600 ºF. The hot gases expand in the power turbine section and spin blades attached to a shaft, transferring heat energy into rotary motion, measured as shaft horsepower.[1]

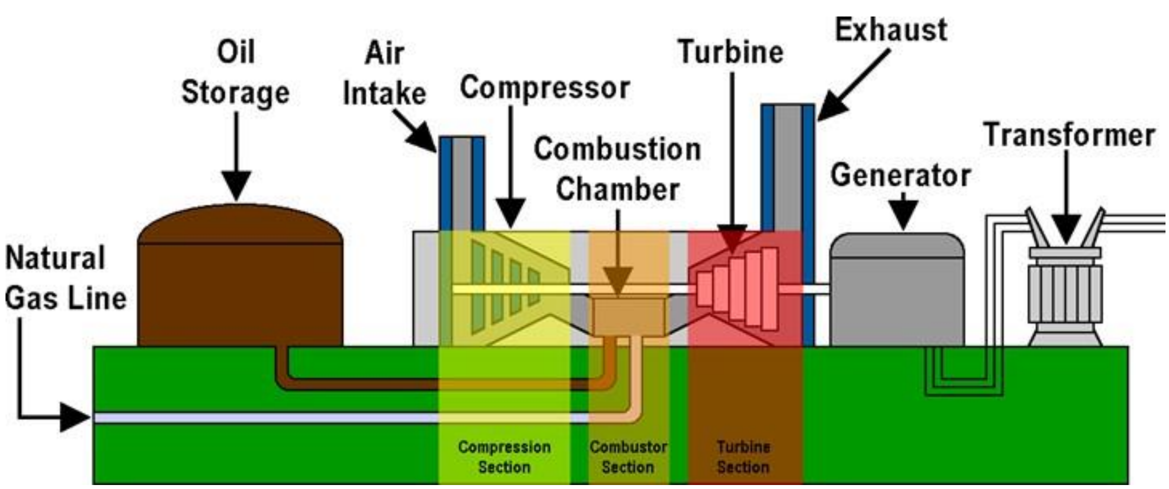

Figure 3.14 - 1: Cross Section of Combustion Turbine Sections

3.14.1.2 Combustion Turbine Cycles

There are four basic operating cycles for gas turbines: simple cycle, regenerative cycle, cogeneration cycle, and combined cycle.

Simple Cycle

A simple cycle turbine is comprised only of the three sections: compressor, combustor, and turbine. The thermal efficiency of simple cycle turbines ranges from 15 to 42%. Simple cycle turbines are not equipped with heat exchangers.

[1] *Compilation of Air Emissions Factors, Volume 1, Chapter 3: Stationary Internal Combustion Sources, Section 3.1: Stationary Gas Turbines,* EPA AP-42, January 1995.

Regenerative Cycle
A simple cycle turbine equipped with an added heat exchanger (recuperator). The heat exchanger uses the hot exhaust gases to preheat the incoming combustion air. Transferring the thermal energy from the exhaust gases to the incoming combustion gases increases the thermal efficiency to 44 to 47%.

Cogeneration Cycle
A simple cycle turbine equipped with an HRSG, using heat from the exhaust gases for space heating, drying, or steam generation. The HRSG can be equipped with duct burners, which combust additional fuel after the turbine to generate more heat, resulting in more steam (creating more energy) in the HRSG. The difference between a cogeneration cycle and combined cycle turbine is the use of the steam; in a cogeneration cycle turbine, the exhaust heat is used for multiple purposes, including generating electricity. An HRSG increases the overall thermal efficiency to as high as 84%.

Combined Cycle
A combined cycle turbine generates electric power in two ways: the turbine drives an electric generator and produced steam is used to power a steam turbine, which also drives an electric generator. The difference between a cogeneration cycle and combined cycle turbine is the use of the steam; in a combined cycle turbine, the steam is solely used in another turbine to generate electricity. The combined cycle turbine can only be used with a HRSG and may be equipped with a duct burner. The combined cycle turbine has a thermal efficiency between 38 and 60%.[2]

3.14.2 SOTA Performance Levels

This SOTA Manual includes operational requirements, emissions limitations, and control efficiency requirements for different air contaminants, depending on the fuel combusted and cycle of the stationary combustion turbine.

3.14.2.1 Maximum Achievable Control Technology for Stationary Combustion Turbines

For formaldehyde (HAP) emissions from applicable stationary combustion turbines, compliance with the provisions of the Maximum Achievable Control Technology (MACT) standard found in Title 40 of the Code of Federal Regulations (CFR), Part 63, Subpart YYYY, National Emission Standards for Hazardous Air Pollutants (NESHAP): Stationary Combustion Turbines[3] is considered equivalent to SOTA, pursuant to N.J.A.C. 7:27-8.12(e)(3) for preconstruction permits and N.J.A.C. 7:27-22.35(c) for operating permits. Emissions of other air contaminant emissions from stationary combustion turbines not subject to the MACT standard are addressed in other sections of this SOTA manual.

Stationary combustion turbines (excluding duct burners or heat recovery units) that are located at a major source of HAP are subject to the MACT standard. The MACT standard includes a formaldehyde emissions limit of 91 parts per billion by volume, dry basis (ppbvd) at 15% oxygen (O_2) that applies to all turbine operating time except startup. The emissions limit only applies to stationary combustion turbines that meet all the following requirements:

1. Constructed or reconstructed after January 14, 2003;
2. Combusts fuel oil, natural gas, or less than 10 percent of biogas (as determined by the gross heat input on an annual basis);

[2] *Compilation of Air Emissions Factors, Volume 1, Chapter 3: Stationary Internal Combustion Sources, Section 3.1: Stationary Gas Turbines,* EPA AP-42, January 1995.
[3] Title 40 of the Code of Federal Regulations, Part 63, Subpart YYYY.

3. Peak power output rating of 1.0 megawatt or more at International Organization for Standardization (ISO) standard conditions;
4. Uses lean premix or diffusion flame technology to combine the air and the oil or natural gas in the combustion chamber;
5. Not located at a research or laboratory facility where the research is being conducted on the turbine itself; and
6. Not located on a turbine test cell or stand.

HRSG and duct burners are not included in the MACT standard. Stationary combustion turbines that do not meet the applicability requirements of the formaldehyde emissions limit may still be subject to monitoring, recordkeeping, and reporting requirements of the MACT Standard.

3.14.2.2 New Source Performance Standards for Stationary Combustion Turbines

EPA has developed new source performance standards (NSPS) in 40 CFR, Part 60, Subpart KKKK[4] for stationary combustion turbines that were constructed, modified, or reconstructed after February 18, 2005. The regulation also applies to duct burners and HRSG. It contains emissions limits and control requirements for nitrogen oxides (NO_X) and sulfur dioxide (SO_2). Since the NO_X emissions limits are less stringent than the emissions limits determined to be SOTA in Section 3.14.2.5, they are not included in this manual.

Stationary combustion turbines subject to 40 CFR, Part 60, Subpart KKKK have several options for SO_2 emissions limits:

1. Exhaust Emissions Limit: 0.90 pounds SO_2 per megawatt-hour (lbs. SO_2/MW-hour);
2. Fuel Sulfur Content: Sulfur content of each fuel combusted is 0.060 lbs. SO_2 per MMBtu. This can be achieved by combusting:
   A. Fuel oil containing 0.05% by weight (500 parts per million by weight – ppmw) or less, or
   B. Natural gas containing 20 grains of sulfur per 100 standard cubic feet or less; or
3. Biogas: 0.15 lbs. SO_2/MMBtu for combustion of 50% or more of biogas in a calendar month.

Note: *Although 40 CFR, Part 60, Subpart GG applies to stationary gas turbines constructed, modified, or reconstructed after October 3, 1977, this SOTA Manual is expected to only be used for stationary combustion turbines subject to 40 CFR, Part 60, Subpart KKKK.*

3.14.2.3 New Source Performance Standards for Electric Generating Units

EPA has developed NSPS in 40 CFR, Part 60, Subpart TTTT[5] for stationary combustion turbines that were constructed, modified, or reconstructed after January 8, 2014, has a base load rating greater than 250 MMBtu/h of fossil fuel (either alone or in combination with any other fuel) and serves a generator or generators capable of selling greater than 25 MW of electricity to a utility power distribution system. The regulation also applies to duct burners and HRSG. It contains emissions limits and control requirements for carbon dioxide (CO_2).

Stationary combustion turbines that combust more than 90% of natural gas on a 12-opreating-month rolling average basis are subject to 40 CFR, Part 60, Subpart TTTT. There are different CO_2 emissions limits, depending on the amount of net electric sales:

[4] Title 40 of the Code of Federal Regulations, Part 60, Subpart KKKK.
[5] Title 40 of the Code of Federal Regulations, Part 60, Subpart TTTT.

1. Turbines that supply more than its design efficiency or 50 percent, whichever is less, times its potential electric output as net-electric sales on both a 12-operating month and a 3-year rolling average basis: 1,000 lbs. CO_2/MW-hour of gross energy output;
2. Turbines that supply its design efficiency or 50 percent, whichever is less, times its potential electric output or less as net-electric sales on either a 12-operating month or a 3-year rolling average basis: 120 lbs. CO_2/MW-hour of gross energy output; or
3. All other turbines: 120 to 160 lbs. CO_2/MW-hour of gross energy output, as determined by the procedures specified in § 40CFR 60.5525.

Note: *On May 23, 2023, EPA proposed a modification to 40 CFR, Part 60, Subpart TTTT that would change the CO_2 emissions limits for stationary combustion turbines serving as electric generating units and expand the applicability of the rule to additional stationary combustion turbines serving as electric generating units. 40 CFR, Part 60, Subpart TTTTa would be applicable to stationary combustion turbines serving as electric generating units constructed, modified, or reconstructed after May 23, 2023.*

3.14.2.4 Emissions Guidelines for Existing Electric Utility Generating Units Existing on or Before January 8, 2014

EPA has not approved requirements for stationary combustion turbines that were constructed, modified, or reconstructed on or before January 8, 2014.[6]

Note: *On May 23, 2023, EPA proposed a modification to 40 CFR, Part 60, Subpart UUUUa that establishes new requirements for developing CO_2 emissions regulations from stationary combustion turbines serving as electric generating units. Any regulations developed to comply with 40 CFR, Part 60, Subpart UUUUa will be applicable to stationary combustion turbines serving as electric generating units constructed, modified, or reconstructed on or before May 23, 2023.*

3.14.2.5 Other SOTA Performance Levels for Stationary Combustion Turbines

The SOTA performance levels for SO_2, TSP, opacity, CO_2 applicable during steady state operations while combusting gaseous fuels or liquid fuels are provided below:

1. SO_2 emissions limits for any stationary combustion turbine using #2 fuel oil (diesel fuel) with a Seconds, Saybolt Universal (SSU) viscosity of 45 or less at 100 ºF: 0.00160 lbs. SO_2/MMBtu or a fuel sulfur content of 15.0 ppmw.[7]
2. Total suspended particulate (TSP) emissions limits:
   A. 0.01 lbs./MMBtu for stationary combustion turbines firing natural gas;
   B. 0.01 lbs./MMBtu for stationary combustion turbines firing fuel oil <150 MMBtu/hour; or
   C. 0.02 lbs./MMBtu for simple cycle stationary combustion turbines firing fuel oil ≥150 MMBtu/hour.[8]
3. An opacity limit of 10% for all operations when firing gaseous fuels and for all operations EXCEPT startup, shutdown, and fuel switching for liquid fuels. For startup, shutdown, and fuel switching of liquid fuels, the opacity limit is 20%.
4. CO_2 emission limits for any new electric generating units (EGU):
   A. 860 lbs. CO_2/MW-hour gross energy output from a new EGU with a nameplate capacity equal to or greater than 25 Megawatt electric (MWe); or

[6] Title 40 of the Code of Federal Regulations, Part 60, Subpart UUUUa.
[7] N.J.A.C. 7:27-9.2
[8] SC&A, Inc. *Analysis of Combustion Turbines Permits Emissions Limits and Control Requirements*, March 2023.

B. Case-specific output-based emissions limit for a new EGU with a nameplate capacity less than 25 MWe.[9]

Additional requirements for steady state operation of stationary combustion turbines are included in Tables 3.14.2-1 through 3.14.2-3. These include control equipment and emissions limits for carbon monoxide (CO), NO_X, volatile organic compounds (VOC), and ammonia (NH_3). Liquid fuels include any liquid fuel, (e.g., #2 Fuel Oil, Diesel Fuel, Aviation Kerosene, Distillate Oil, etc.). Natural gas fuels do not include biogas. NH_3 is only emitted from turbines equipped with Selective Catalytic Reduction (SCR) to control NO_X. Cogeneration units that employ duct burners or HRSG are subject to the same emissions limits as the associated turbine.

The emissions limits specified in this SOTA manual do not apply outside of steady state operating conditions. SOTA technology for startup, shutdown, and fuel switching is determined using the case-by-case approach, pursuant to N.J.A.C. 7:27-8.12 and N.J.A.C. 7:27-22.35.

[9] N.J.A.C. 7:27F-2.5

TABLE 3.14.2-1
CO SOTA Steady State Performance Levels and Control Technologies for Stationary Combustion Turbines[10]

Pollutant	Maximum Heat Input (MMBtu/hour)	Cycle	Air Pollution Control Technology	Emissions Concentration (ppmvd @ 15% O_2)	
				Gaseous Fuels	Liquid Fuels
CO	≥10 & <150	Simple & Regenerative	Combustion control technologies	6.0	10
CO	≥150	Simple & Regenerative	Combustion control technologies and CO oxidation catalyst	4.5	5.0
CO	≥10 & <150	Combined	Combustion control technologies	5.0	10
CO	≥150	Combined	Combustion control technologies or CO oxidation catalyst	2.0	2.0
CO	Any Size Natural Gas Compressor	Simple	Oxidation catalyst	1.5[11]	N/A

NOTES:

1. Cogeneration units are subject to the emissions limits for the associated turbine cycle, (i.e., simple/recuperative or combined).
2. Compliance averaging times for CO performance levels for combined cycle units greater than or equal to 150 MMBtu/hour are established by a 3-hour rolling average, based on 1-hour blocks, when a continuous emissions monitoring system (CEMS) is employed. **If a CEMS is not employed, compliance is established using (3) 1-hour test runs.**
3. For natural gas compressors, the provided emissions concentrations are for operations above 0ºF; for operations below 0ºF, the applicant must represent SOTA technology using a case-by-case approach, pursuant to N.J.A.C. 7:27-8.12 and N.J.A.C. 7:27-22.35.

[10] SC&A, Inc. *Analysis of Combustion Turbines Permits Emissions Limits and Control Requirements*, March 2023.
[11] ERM, Significant Modification Application, Compressor Station 505 Neshanic Station, March 2021.

TABLE 3.14.2-2
NO_X / NH_3 SOTA Steady State Performance Levels and Control Technologies for Stationary Combustion Turbines[12]

Pollutant	Maximum Heat Input (MMBtu/hour)	Cycle	Air Pollution Control Technology	Emissions Concentration (ppmvd @ 15% O_2)	
				Gaseous Fuels	Liquid Fuels
NO_X	≥10 & <150	Simple & Regenerative	Dry Low NO_X (DLN) Combustion	10 25 when firing biogas[13]	42
NO_X	≥150	Simple & Regenerative	DLN Combustion & SCR	3.0	4.0
NO_X	≥10 & <150	Combined	DLN Combustion	10	42
NO_X	≥150	Combined	DLN Combustion & SCR	2.5[14]	3.5
NO_X	Any Size Natural Gas Compressor	Simple	DLN Combustion	3.5[15]	N/A
NH_3	≥10 & <150	Simple	Any Equipped with an SCR	5.0	5.0
NH_3	≥150	Simple	Any Equipped with an SCR	5.0	4.0
NH_3	Any Size	Combined	Any Equipped with an SCR	2.0	5.0
NH_3	Any Size Natural Gas Compressor	Simple	Any Equipped with an SCR	10[16]	N/A

NOTES:

1. Cogeneration units are subject to the emissions limits for the associated turbine cycle, (i.e., simple/recuperative or combined).
2. Compliance averaging times for NOx, CO, and VOC performance levels for combined cycle units greater than or equal to 150 MMBtu/hour are established by a 3-hour rolling average, based on 1-hour blocks, when a continuous emissions monitoring system (CEMS) is employed. **If a CEMS is not employed, compliance is established using (3) 1-hour test runs.**
3. For natural gas compressors, the provided emissions concentrations are for operations above 0ºF; for operations below 0ºF, the applicant must represent SOTA technology using a case-by-case approach, pursuant to N.J.A.C. 7:27-8.12 and N.J.A.C. 7:27-22.35.

[12] SC&A, Inc. *Analysis of Combustion Turbines Permits Emissions Limits and Control Requirements*, March 2023, unless otherwise specified.
[13] California Air Resources Board, Rule 1134(d)(1)
[14] California Air Resources Board, Rule 1134, Table I
[15] California Air Resources Board, Rule 1134, Table II
[16] ERM, Significant Modification Application Compressor Station 505 Neshanic Station, March 2021.

TABLE 3.14.2-3
VOC SOTA Steady State Performance Levels and Control Technologies for Stationary Combustion Turbines[17]

Pollutant	Maximum Heat Input (MMBtu/hour)	Cycle	Air Pollution Control Technology	Emissions Concentration (ppmvd @ 15% O_2)	
				Gaseous Fuels	Liquid Fuels
VOC	≥10 & <150	Any Cycle	Combustion control technologies	2.0	2.0
VOC	≥150	Any Cycle	Combustion control technologies or CO oxidation catalyst	2.0	2.0
VOC	Any Size Natural Gas Compressor	Simple	Combustion control technologies or CO oxidation catalyst	2.5[18]	N/A

NOTES:

1. Cogeneration units are subject to the emissions limits for the associated turbine cycle, (i.e., simple/recuperative or combined).
2. Compliance averaging times for VOC performance levels for combined cycle units greater than or equal to 150 MMBtu/hour are established by a 3-hour rolling average, based on 1-hour blocks, when a continuous emissions monitoring system (CEMS) is employed. **If a CEMS is not employed, compliance is established using (3) 1-hour test runs.**
3. For natural gas compressors, the provided emissions concentrations are for operations above 0ºF; for operations below 0ºF, the applicant must represent SOTA technology using a case-by-case approach, pursuant to N.J.A.C. 7:27-8.12 and N.J.A.C. 7:27-22.35.

[17] SC&A, Inc. *Analysis of Combustion Turbines Permits Emissions Limits and Control Requirements*, March 2023.
[18] ERM, Significant Modification Application Compressor Station 505 Neshanic Station, March 2021.

3.14.3 Control Technologies

Reductions in CO, NO_X, and VOC emissions can be achieved using combustion control technologies or flue gas treatment (post-combustion control technologies). SO_2 is primarily controlled by regulating the fuel sulfur content.

3.14.3.1 Combustion Control Technologies for NOX

NO_X controls alter the combustion parameters, changing the combustion chemistry (lower temperature, excess oxygen, and reduced residence time). NO_X is formed from nitrogen in the fuel (Fuel NO_X) and atmosphere (thermal NO_X) combining with excess oxygen in the combustor section. Dry controls are any controls that do not use water or steam injection.

Lean Combustion
A/F ratios greater than 1.0 are considered fuel-lean conditions, (excess air). With lean combustion, excess air results in a cooler flame, reducing peak flame temperature and thermal NO_X formation. Lean combustion can occur with air and fuel mixed at a greater A/F ratio before or in the combustion chamber (premix) or where fuel and air are injected into the combustion chamber and mix via diffusion during combustion (diffusion flame).

Reduced Combustor Residence Time
In all gas turbine combustor designs, the high temperature combustion gases exiting the combustor are cooled with dilution air prior to entering the turbine. Reduced residence time combustors add dilution air sooner than standard combustors. Because the combustion gases are at a high temperature for a reduced time, the amount of thermal NO_X generated decreases.

Rich/Quench/Lean Combustion (RQL)
RQL combustors burn in fuel-rich conditions (rich combustion or A/F less than 1.0) in a primary combustor zone and fuel-lean in a secondary combustor zone. Incomplete combustion in the fuel-rich primary zone produces exhaust gases with a high concentration of CO and hydrogen gas (H_2). The CO and H_2 replaces some of the oxygen for NO_X formation and acts as a reducing agent for any Fuel NO_X formed from nitrogen in the fuel within the primary zone. The lower peak flame temperatures due to partial combustion in the primary combustor zone reduces the formation of thermal NO_X in the secondary combustor zone. This is an effective control for both Thermal and Fuel NO_X.

Flameless Catalytic Combustion System
A catalyst module is added to the combustor, allowing for partial combustion of the fuel that produces no NO_X. The remaining fuel is combusted in the combustor at a lower temperature.

Selective Catalytic Reduction (SCR)
SCR is an add-on NO_X control technique that is placed in the exhaust stream following the gas turbine. SCR is a process in which ammonia is directly injected into the flue gas and then passed over a catalyst to react with NO_X, converting the NO_X, and ammonia to nitrogen and water. The catalyst allows this reaction to take place at a lower temperature than would be required without it. The temperature of the catalyst should be between approximately 570 ºF to 750 ºF depending on the catalyst used. The catalyst is usually either a noble metal, base metal (titanium or vanadium), or a zeolite-based material. SCR is a common technique for combined cycle turbines. It has also been used in some simple cycle applications.

Catalytic Absorption System Without Ammonia Injection

This system utilizes a single catalyst for the removal of both CO and NO_X emissions. The catalyst works by simultaneously oxidizing CO to carbon dioxide (CO_2), NO to NO_2, and then absorbing NO_2 onto its surface via a potassium carbonate coating on the absorber. During this cycle, the potassium carbonate coating reacts to form potassium nitrites and nitrates, which are then present on the surface of the catalyst. When the surface of the catalyst becomes saturated, the catalyst must be regenerated, as it no longer is reacting with NO_X. The regeneration cycle is accomplished by passing a dilute H_2 reducing gas across the surface of the catalyst in the absence of the oxygen.

Wet Control - Water or Steam Injection

Water or steam injection reduces thermal NO_X formation by reducing the combustion turbine flame temperature. Water or steam is injected into the turbine combustor, reducing flame temperatures by dilution and evaporative cooling of combustion products. The result is a lower flame temperature and reduced formation of thermal NO_X. Injection rates for both water and steam are usually described by a water/steam-to-fuel ratio and are usually given on a weight basis. The injection ratio is the most significant factor affecting the performance of this control technology. Higher ratios result in greater NO_X reductions but may increase emissions of CO and VOC, reduce turbine efficiency, and increase turbine maintenance requirements.

3.14.3.2 CO and VOC Control Technology

Combustion Controls

Combustion controls involve optimizing the factors effecting combustion chemistry (i.e., temperature, excess oxygen, and residence time) to minimize emissions of CO, VOC, and other products of incomplete combustion (PIC's) as well as NO_X in a balanced manner. Sometimes efforts to control NO_X cause increases in PICs, so it is important to ensure CO and other PIC emissions do not increase significantly when controlling NO_X. This is done by careful control of the combustion parameters, as well as add on oxidation catalysts.

Oxidation Catalyst (Post Combustion Control)

An oxidation catalyst can be used to reduce emissions of CO, VOC, and other PICs. For effective combustion of PICs, the flue gas must be fuel-lean (excess oxygen) and at the proper operating temperature. There are several catalysts available to reduce emissions of CO and VOC.

3.14.3.3 Alternate Control Technologies - Energy Efficiency

Greater energy efficiency reduces emissions of all air contaminants, including CO_2, a greenhouse gas. Higher efficiency processes include cogeneration and combined heat and power (CHP) generation. For electric generation in combined cycle turbines, the energy efficiency of the process is expressed in terms of MMBtu per Megawatt-hour (MW-hr) and must be reported in the permit application. Cogeneration combustion turbines that generate steam for uses in addition to electricity generation would have even lower emissions rates per MW-hr. Cogeneration CHP units that generate steam and electrical power have much higher efficiencies, typically 70% to 80%, compared to a 40% efficiency for a simple cycle turbine or a 60% efficiency for a combined cycle turbine.

To calculate lbs./MW-hr for cogeneration units, useful steam energy must be converted to equivalent MW-hr and added to the electric output. U.S. EPA has published "A handbook for Air Regulators – Output based Regulations" which provides the conversion factor and different approaches on how to convert steam output into equivalent MW-hr. Energy efficiency programs are encouraged to increase the use of otherwise wasted thermal energy. If employed as part of a turbine, cogeneration units are subject to the emissions limits within this SOTA manual for the associated turbine cycle, (i.e., simple/recuperative or combined). Cogeneration units that employ duct burners or HRSG are subject to the same emissions limits as the associated turbine.

3.14.4 Technical Basis

Information from the following sources were used as the basis for developing this SOTA Manual:

A. Title 40 of the Code of Federal Regulations, Part 60, Subpart KKKK, "Standards of Performance for Stationary Combustion Turbines."

B. Title 40 of the Code of Federal Regulations, Part 60, Subpart TTTT, "Standards of Performance for Greenhouse Gas Emissions for Electric Generating Units."

C. Title 40 of the Code of Federal Regulations, Part 60, Subpart UUUUa, "Emission Guidelines for Greenhouse Gas Emissions From Existing Electric Utility Generating Units."

D. Title 40 of the Code of Federal Regulations, Part 63, Subpart YYYY, "National Emission Standards for Hazardous Air Pollutants: Stationary Combustion Turbines."

E. State of California, Air Resources Board, "Guidance for the Permitting of Electrical Generation Technologies."

F. State of California, Air Resources Board, "Emissions of Oxides of Nitrogen from Stationary Gas Turbines."

G. SC&A, Inc. *Analysis of Combustion Turbines Permits Emissions Limits and Control Requirements*, February 15, 2023.

3.14.5 Recommended Review Schedule

This SOTA Manual will be reviewed periodically and revised if new collection and control technologies that minimize emissions become available, and any time a new MACT standard or standard of performance for new or existing sources is published.