Natural Gas- and Oil-fired Steam Generating Unit
Technical Support Document

New Source Performance Standards for Greenhouse Gas Emissions from New, Modified, and Reconstructed Fossil Fuel-Fired Electric Generating Units; Emissions Guidelines for Greenhouse Gas Emissions from Existing Fossil Fuel-Fired Electric Generating Units; and Repeal of the Affordable Clean Energy Rule Proposal

Docket ID No. EPA-HQ-OAR-2023-0072

U.S. Environmental Protection Agency
Office of Air and Radiation
March 2023

Summary

Emission rates of natural gas- and oil-fired steam generating units depend on capacity factor, and are otherwise relatively uniform between units. It is therefore reasonable to define subcategories for these types of units based on capacity factor with respective presumptive emission standards. Emission rates are stable, and relatively uniform above capacity factors of around 8 percent. For natural gas-fired units, units with annual capacity factors greater than or equal to 8 percent and less than 45 percent mostly operate with annual emission rates less than 1500 lb CO_2/MWh-gross, while units with annual capacity factors greater than or equal to 45 percent mostly operate with annual emission rates less than 1300 lb CO_2/MWh-gross. There are few, if any, continental oil-fired units with capacity factors greater than 8 percent. Those few that have reported higher capacity factors predominantly fire natural gas at nearly 90 percent or more during most operating years and can thereby achieve the same emission rates as natural gas-fired units.

Overview

Natural gas- and oil-fired steam generating units combust natural gas, oil, and other fuels in a boiler to produce steam which is converted to electricity in a steam turbine for distribution to the electric grid. The combustion of fossil fuels results in the emission of CO_2. Natural gas- and oil-fired steam generating units operate at various loads (*i.e.*, capacity factors). Steam generating units are, in general, designed to be the most efficient when operating at or near their nameplate capacity (*i.e.*, their maximum rated capacity on an electricity generation basis). When units operate at lower loads, they tend to operate less efficiently and CO_2 emission rates, relative to gross generation, can be higher. In this document, the CO_2 emission rates of natural gas- and oil-fired steam generating units are evaluated relative to capacity factor. Details of methods are provided in Appendix A.

1. Capacity Factors of Continental Natural Gas- and Oil-fired Steam Generating Units

Most natural gas-fired steam generating units operate with annual capacity factors less than 10 percent, as shown in figure 1.

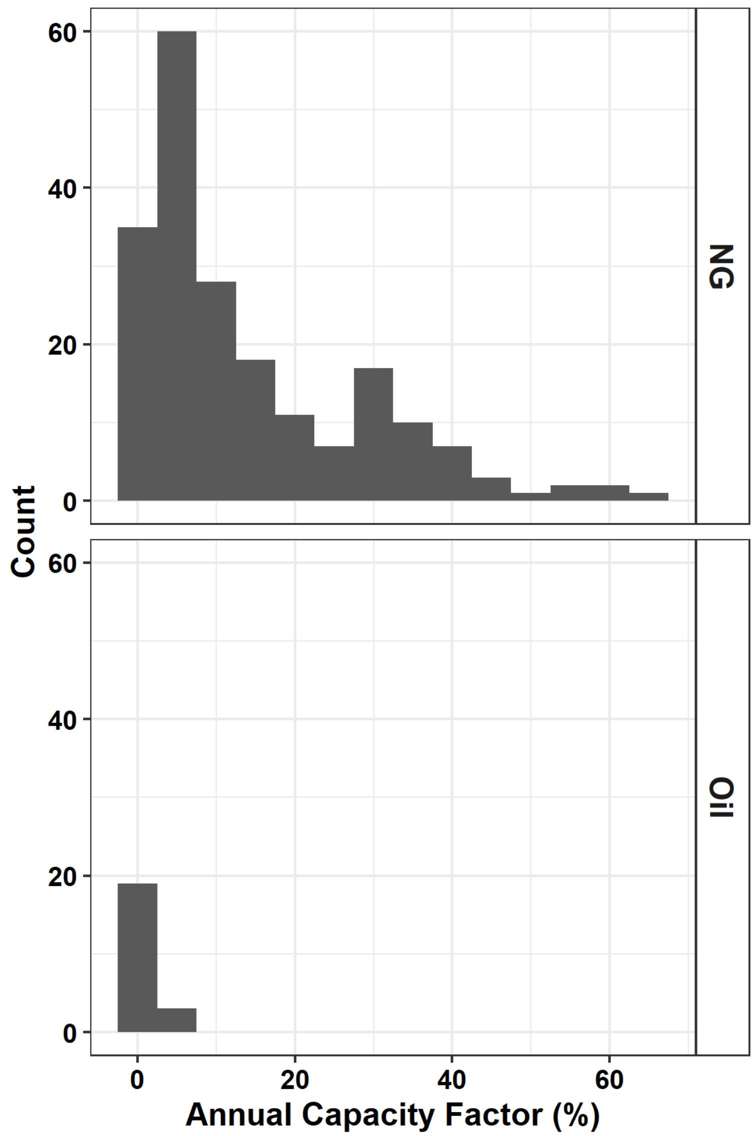

Figure 1: Annual capacity factors for 2019 based on Clean Air Markets Program Data (CAMPD.

For natural gas-fired steam generating units in 2019, 199 units with a capacity of 53 GW were identified and had an average annual capacity factor of 14.3 percent. More than 50 percent of units had annual capacity factors less than 10 percent, 75 percent of units had annual capacity factors less than 22 percent, and 90 percent of units had annual capacity factors less than 35 percent. For oil-fired steam generating units in 2019, 22 units were identified with a capacity of 11 GW and had an average annual capacity factor of 1.2 percent. About 50 percent of units had annual capacity factors less than 0.4 percent, more than 75 percent of units had capacity factors less than 1.6 percent, and more than 90 percent of units had capacity factors less than 2.7 percent.

2. CO_2 Emission Rates of Natural Gas- and Oil-fired Steam Generating Units

Annual CO_2 emission rates relative to annual capacity factor is shown in figure 2 for units with capacity factors less than 8 percent and in figure 3 for units with capacity factors greater than or equal to 8 percent. There are no, or very few, units that were identified that fired oil and operated with capacity factors greater than or equal to 8 percent. A few units were identified with higher capacity factors, however, these units predominantly fired natural gas at levels over 80 percent on average, and are discussed in detail in section 2.b.i of this document. Capacity factors above 8 percent are relatively stable. Furthermore, compared to coal-fired units which have annual emission rates can vary between units from 1700 to 2500 lb CO_2/MWh-gross even at annual capacity factors above 80 percent, the emission rates of natural gas- and oil-fired steam generating units with capacity factors above 8 percent are relatively consistent between units and typically vary from about 1200 lb CO_2/MWh-gross to around 1500 lb CO_2/MWh-gross.

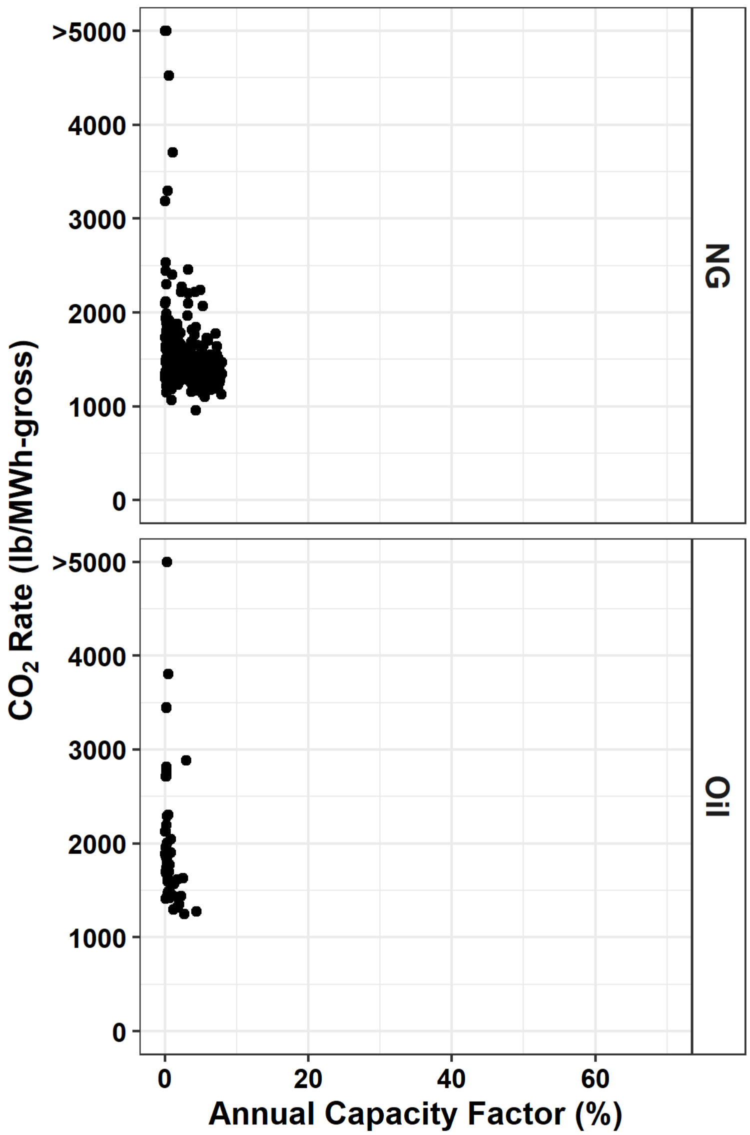

Figure 2: Annual CO_2 emission rates (lb/MWh-gross) vs annual capacity factors, data from 2015 through 2021, for units with capacity factors less than 8 percent.

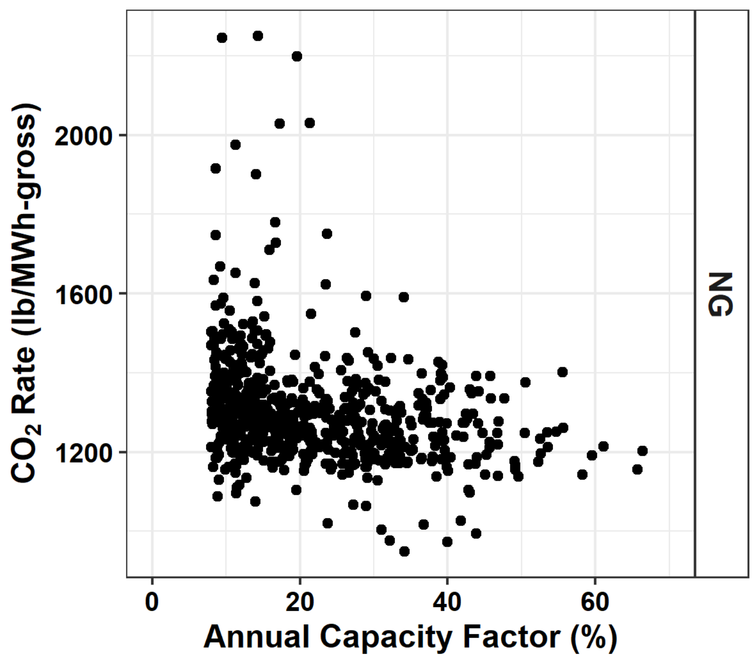

Figure 3: Annual CO_2 emission rates (lb/MWh-gross) vs annual capacity factors, data from 2015 through 2021, for natural gas-fired units with capacity factors greater than or equal to 8 percent.

a. CO_2 Emission Rates for Natural Gas-fired Steam Generating Units

Natural gas-fired units with low annual capacity factors have variable emission rates. For 159 units with capacity factors less than 8 percent, 50 percent of units have a maximum emission rate less than 1450 lb CO_2/MWh-gross and about 90 percent of units have a maximum emission rate less than about 2500 lb CO_2/MWh-gross, and some units have emission rates above 5000 lb CO_2/MWh-gross. It may therefore be challenging to define presumptive standards for those units.

Natural gas-fired units with intermediate capacity factors have relatively stable, lower emission rates. For 157 units with capacity factors greater than 8 percent and less than 45 percent, 50 percent of units never exceed an emission rate of 1323 lb CO_2/MWh-gross, about 75 percent of units never exceed an emission rate of 1400 lb CO_2/MWh-gross, about 90 percent of units never exceed an emission rate of 1500 lb CO_2/MWh-gross, and more than 95 percent of units never exceed an emission rate of 1600 lb CO_2/MWh-gross.

For 148 units with capacity factors greater than 10 percent and less than 50 percent, 50 percent of units never exceed an emission rate of 1310 lb CO_2/MWh-gross, 75 percent of units never exceed an emission rate of 1400 lb CO_2/MWh-gross, 90 percent of units never exceed an emission rate of 1500 lb CO_2/MWh-gross, and 95 percent of units never exceed an emission rate of 1572 lb CO_2/MWh-gross.

Natural gas-fired units with high annual capacity factors (*i.e.*, base load units) have lower emission rates. For 25 units with capacity factors greater than 40 percent, 50 percent of units never exceed an emission rate of 1250 lb CO_2/MWh-gross, 75 percent of units never exceed an emission rate of 1300 lb CO_2/MWh-gross, 90 percent of units never exceed an emission rate of 1361 lb CO_2/MWh-gross, and 95 percent of units never exceed an emission rate of 1387 lb CO_2/MWh-gross.

For 9 units with capacity factors greater than 50 percent, 50 percent of units never exceed an emission rate of 1234 lb/MWh-gross, 75 percent of units never exceed an emission rate of 1250 lb CO_2/MWh-gross, about 90 percent of units never exceed an emission rate greater than 1380 lb CO_2/MWh-gross, and 95 percent of units never exceed an emission rate of 1392 lb CO_2/MWh-gross.

To expand the data set, it can be helpful to evaluate units with similar operating profiles. About 90 percent of units with capacity factors greater than 40 percent have duty cycles great than 50 percent.

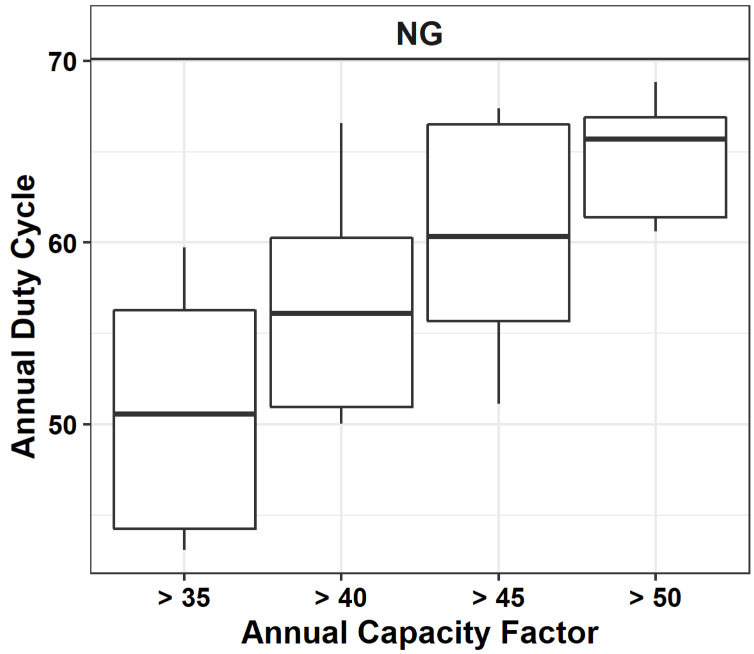

Figure 4: Boxplot of minimum annual duty cycle versus capacity factor group. Outer lines mark the 10th and 90th percentiles. Outer edges of the boxes mark the 25th and 75th percentiles. Center lines mark the 50th percentiles.

Units with higher duty cycles operate more efficiently and with lower emission rates. For the 54 units with duty cycles greater than 50 percent and capacity factors greater than 20 percent, 50 percent of units never exceed an emission rate of 1252 lb CO_2/MWh-gross, 75 percent of units never exceed an emission rate of 1330 lb CO_2/MWh-gross, 90 percent of units never exceed an emission rate of 1390 lb CO_2/MWh-gross, and 95 percent of units never exceed an emission rate of 1414 lb CO_2/MWh-gross.

Based on the analyses above, it is reasonable to define subcategories for natural gas-fired steam generating units based on capacity factor and, for the intermediate and base load subcategories, determine presumptive standards on a fleetwide basis.

b. CO_2 Emission Rates for Oil-fired Steam Generating Units

There are likely no or very few oil-fired steam generating units with capacity factors greater than 8 percent in the continental U.S. Emission rates for units. As evidenced by the data in figure 2, emission rates for oil-fired units with low capacity factor can vary considerably.

i. Units Near the Threshold for Oil-firing

Excluded from the calculations in section 2.a. of this document were the units at two power plants which alternated between natural gas- and oil-fired status between 2015 and 2021. In 2019, two units at those facilities were the only units from across the fleet that met the proposed definition for oil-fired steam generating units while having annual capacity factors greater than 8 percent (10.7 percent – Northport Unit 1; 10.9 percent – Port Jefferson Unit 4). Both fired significant proportions of natural gas (92.9 percent – Northport Unit 1; 97.9 percent – Port Jefferson Unit 4) in 2019 but exceeded the threshold for oil-fired classification (greater than 15 percent oil firing) in at least one of the other two years in the past three years. Between 2019 and 2021, the four natural gas- and oil-fired steam generating units at Northport had a cumulative heat input fraction from natural gas of 94.9 percent, an average capacity factor of 23.3 percent, and an average CO_2 emission rate of 1240 lb CO_2/MWh-gross. Between 2019 and 2021, the two natural gas- and oil-fired steam generating units at Port Jefferson had a cumulative heat input fraction from natural gas of 92.2 percent, an average capacity factor of 12.9 percent, 1290 lb CO_2/MWh-gross.

This suggests that while there could be units that would be classified as oil-firing at intermediate and base load, they would likely be able to achieve emission rates consistent with natural gas-firing because they fire high levels of natural gas on average.

ii. High Duty Cycle Units Firing Mostly Oil

Although units that fire 90 percent or more of their heat input on oil in the continental U.S. usually operate with low annual capacity factors, some units operate with higher annual duty cycles. Those units with higher duty cycles may be representative of the emission rates that could be achievable if units were to operate at higher capacity factors, as shown in figure 5. Based on figure 5, considering the low annual capacity factors of this data influence the observed emission rates, it may be reasonable to anticipate that an intermediate load oil-fired unit could operate with emission rates less than 2000 lb CO_2/MWh-gross and a base load unit could operate with emission rates less than 1800 lb CO_2/MWh-gross. However, based on historical data, oil-fired units operating with capacity factors greater than 8 percent appears to be an unlikely scenario.

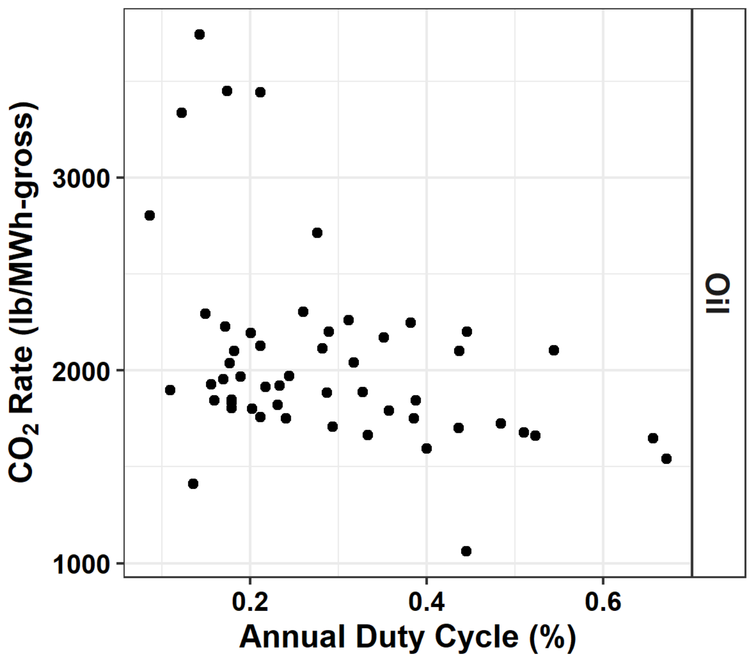

Figure 5: Emission rates vs duty cycle for oil-fired steam generating units.

Appendix A: Methods

Supporting data for the analysis, figures, and tables in this document are available in the attached Excel workbook *Natural Gas- and Oil-fired Steam Generating Unit - Supporting Data.xlsx*.

A.1. EIA923 fuel data:

EIA form 923 reports generation data by mover (source) type for power plants connected to the electric grid. EIA form 923 data were accessed from https://www.eia.gov/electricity/data/eia923/. The third sheet (Page 3 Boiler Fuel Data) for each year were compiled in R into a single data frame. Data were filtered to exclude years prior to 2015 and data from combined heat and power plants. Fuel use data were summarized for each data year for steam generating units (reported prime mover of "ST" – steam turbine) for each unique combination of facility identifier (ORIS plant code) and boiler identifier (boiler ID).

A.2. CAMD Data

Facility level data (2015-2021) and annual emission data (2015-2021) were accessed through the CAMPD custom data download tool (https://campd.epa.gov/data/custom-data-download). Data were filtered to exclude units other than steam generating units (unit type "boiler"). Nameplate capacity was determined based on the information reported in the CAMPD facility level data and matched back to the turbine's unit ID. Additional unit level information from NEEDS () and EIA form 860 () were incorporated into the data set. Annual boiler level fuel use data from EIA form 923 (noted above) were also incorporated, as were EIA form 923 plant level disposition data (EIA923 Schedules 6-7, "Source and disposition"). Units were dropped from subsequent analyses if they were not steam generating units, if the boiler to steam turbine ration was not 1-to-1, fired only coal, fired significant amounts of non-fossil fuels, were smaller than 25 MW, were at plants with low disposition to the electric grid, or if they were associated with combined heat and power. One facility was an outlier with abnormally high annual emission rates (greater than 2000 lb CO_2/MWh-gross) at high annual capacity factors (greater than 80 percent) was excluded that fired roughly 90 percent natural gas and 10 percent biomass solids, and was excluded from further analysis.

A.2.1. Annual CAMD Data

After filtering the units on the preceding criteria, annual (calendar year) capacity factors for each unit were determined by dividing the total gross generation (MWh) by the product of the unit's nameplate capacity (MW) and the total number of hours in that calendar year (8760 hours for most years and 8784 hours for leap years). Annual duty cycles were similarly calculated relative to the sum of operating hours in a year. Annual emission rates were calculated by dividing the sum of CO_2 emissions over the annual generation.