Assessment of startup period at coal-fired electric generating units - Revised

U.S. Environmental Protection Agency, Office of Air and Radiation

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1. Purpose

This analysis explores the time and gross load levels (hourly electricity generation as a percentage of nameplate capacity) necessary for coal-fired electric utility steam generating units (EGUs) to engage and operate air pollution control devices (APCDs). The analysis uses historical electricity output, heat input, and emission data, along with EGU characteristics and APCD information from 2011 and 2012 as indicators to assess operation of APCDs at coal-fired EGUs. The analysis includes two parts – (a) an analysis of all startup events at all coal-fired EGUs, and (b) an analysis of startup events at the best performing 12 percent of coal-fired EGUs.[1] These results facilitate the identification of the start of APCD operation.

Abbreviations

APCD	air pollution control device(s)	MMBtu	million British thermal units (unit of energy)
CEMS	continuous emission monitoring system	MW	megawatt(s) – one million watts
CFB	circulating fluidized bed – boiler type	NO_X	nitrogen oxides
CO_2	carbon dioxide	PC	pulverized coal – boiler type
EGU	electric utility steam generating unit	PPM	parts per million
EPA	(U.S.) Environmental Protection Agency	SCR	selective catalytic reduction – NO_X control
FGD	flue gas desulfurization – SO_2 and acid gases control	SO_2	sulfur dioxide

Definitions

Emission rates: average mass emissions (in pounds) released per million British thermal unit (MMBtu) of heat input

Failed start: a startup event in which the EGU begins combusting fossil fuel and subsequently ceases combusting fossil fuel without generating any electricity. Failed starts may be planned or unplanned, and often occur when bringing a plant online after a maintenance outage.

Normal start: a startup event in which the EGU begins combusting fossil fuel and generates some measurable amount of electricity before ceasing fossil fuel combustion.

Startup event: initiation of fossil fuel combustion at an EGU following one or more hours of non-operation (i.e., no combustion)

- Hot start:[a] A startup event in which the EGU was offline for 24 hours or less before starting to combust fossil fuels
- Warm start:[a] A startup event in which the EGU was offline for 25 - 119 hours before starting to combust fossil fuels
- Cold start:[a] A startup event in which the EGU was offline for 120 hours or more before starting to combust fossil fuels

[a] Hot, warm, and cold starts are defined using turbine metrics presented in Lefton and Hilleman, "Is your plant ready for cycling operations?" *Power Magazine*; 2011.

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[1] Clean Air Act section 112(h)(1) requires work practice standards to be established "consistent with the provisions of subsections [112](d) or (f) of this sections." The EPA interprets that provision as requiring work practice standards to be based on the performance of the best performing sources in the category or subcategory. For EGUs startup and shutdown, the EPA defines best performing EGUs by determining the EGUs that are able to bring their pollution controls on line the most efficiently. See the preamble to the final rule and the response to comments for additional discussion on this issue.

2. Introduction

The EPA received several comments concerning our definition of the end of startup in response to the proposed reconsideration of startup/shutdown issues for the Mercury and Air Toxics Standards (MATS) Rule. Several commenters advocated that the startup period should not end when the EGU begins generating electricity or useful thermal energy. Rather, commenters argued that startup should end at different times depending on whether the EGU was subcritical or supercritical, and on the types of controls that were installed. Commenters stated that some APCDs, such as selective catalytic reduction (SCR), need up to 12 hours after electricity generation begins before they become operational. They also stated that circulating fluidized bed (CFB) EGUs become operationally stable only after they reach approximately 40 percent load.

The EPA examined available data concerning the types of EGUs on which the commenters focused: subcritical and supercritical EGUs with flue gas desulfurization (FGD) and SCR controls, and CFB EGUs. This assessment required an hour-by-hour analysis of startup events using emission measurements (from continuous emission monitoring systems (CEMS)), heat input, and electricity (gross) output data from the EPA's Clean Air Markets Database[2] for the types of EGUs identified by the commenters. Using these data, the EPA calculated the average time, in hours, for specific types of EGUs to achieve decile and quartile load bins (e.g., 10 percent, 20 percent, and 25 percent of nameplate capacity) and for SO_2 and NO_X APCDs to begin reducing SO_2 and NO_X emission rates, respectively. In addition, the EPA analyzed the time required for emissions to decline at the best performing 12 percent of coal-fired EGUs – EGUs that were able to, on an annual average, initiate operation of their SO_2 or NO_X APCDs in the least amount of time following the start of generation. The analysis focused on SO_2 and NO_X emissions because the EPA believes that emissions will be sufficiently stable and consistent at this time to accurately measure HAP emissions. In addition, (a) SO_2 emissions serve as a surrogate for acid gas hazardous air pollutants (HAP), (b) FGD and SCR can impact mercury levels[3] and the effectiveness of mercury controls, and (c) changes in SO_2 and NO_X emissions is a measure that can indicate when APCDs are operational. This study does not include assessments of PM control devices (e.g., baghouses, electrostatic precipitators) because hourly PM data were not available; however, comments and other information in the record demonstrate that the best performing EGUs are able to sufficiently warm the PM control devices to operational temperature on clean fuels alone (i.e., within 1 hour of charging coal to the boiler).

This analysis provides information on the startup process and the time required for SO_2 and NO_X APCDs to become operational at coal-fired EGUs. While the actual decision of when to initiate an APCD is affected by a variety of factors, including the type of control device, local weather conditions, flue gas temperature, and safety concerns, this analysis is intended to determine the average time required to initiate APCDs at all coal-fired EGUs and also at the best performing coal-fired EGUs. The EPA believes that the removal efficacy of APCDs, as evidenced by hourly emission rates below uncontrolled levels, is an appropriate indicator of the time the APCDs are operating and provide an appropriate metric for defining the end of the startup period for the purpose of the MATS rule because we are confident HAP emissions can be accurately measured at this time.

[2] The aggregated data set used in this analysis are included in docket ID EPA-HQ-OAR-2009-0234; full data are available from the Clean Air Markets Database [http://ampd.epa.gov/ampd].

[3] Some formulations of catalyst are capable of enhancing the oxidation of mercury, promoting greater capture by downstream APCDs (e.g., wet scrubbers (FGD)).

3. Data and methodology

The EPA collects the emission data analyzed in this paper under 40 CFR Part 75.[4] Most fossil fuel-fired EGUs report hourly emissions (e.g., SO_2, NO_X, CO_2), stack gas flow, and operations (e.g., operating time, heat input, gross electricity generation) data on a quarterly basis.[5] These data were used to identify all startup events at 414 subcritical and supercritical EGUs with FGD and/or SCR APCDs and CFB boiler EGUs[6] during calendar years 2011 and 2012.

This study is intended to assess commenters' claims that there are performance differences among combustion technologies and APCDs as they relate to startup events, and to identify the average number of hours after the start of generation that is necessary to startup SO_2 and NO_X APCDs at the coal-fired EGU fleet generally and at the best performing 12 percent of EGUs. In light of the comments received and to facilitate this assessment, we examined operating data by boiler type (PC supercritical, PC subcritical, and CFB boilers) and by APCD type. For SO_2 emissions, we examined PC boilers with FGD and CFB EGUs. For NO_X emissions, we examined PC supercritical and PC subcritical boilers with SCR.

We excluded cogeneration EGUs from this analysis because adequate steam production data were not available. In addition, because the focus of the analysis is on the time it takes to engage the identified APCDs, coal-fired EGUs without FGD and/or SCR APCDs as of January 1, 2011, were excluded from the analysis.[7] Finally, we excluded data during operating hours with the most conservative substitute data (i.e., maximum potential concentration, maximum potential flow)[8] because these data do not represent actual emissions.

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[4] Supercritical boiler type is drawn from EIA form 860 and EPA research. The analysis data set noted above includes this field.

[5] Sources report data at the monitor (stack) level but this study used data apportioned to the EGU. For more information about Part 75, see the *Plain English Guide to the Part 75 Rule* at www.epa.gov/airmarkets/emissions/docs/plain_english_guide_part75_rule.pdf

[6] CFB boiler technologies are capable of controlling SO_2 by injecting limestone in the combustion bed. Per the definition of "dry flue gas desulfurization technology" in 40 CFR 63.10042, "[a]lkaline sorbent injection systems in fluidized bed combustors (FBC) or circulating fluidized bed (CFB) boilers..." are considered to be FGD technologies (APCDs).

[7] When a comparison is made between "uncontrolled" and "controlled" EGUs, the uncontrolled data represent startup events at EGUs that did not have the relevant APCD. In other words, uncontrolled SO_2 emission rates are based on PC EGUs that have installed SCR, and therefore are a part of the data set, but have not installed an FGD APCD. For NO_X, "non-SCR" startup events are based on PC EGUs that have installed FGD but do not have an SCR. These EGUs may, however, have other NO_X controls such as low-NO_X burners, overfire air, and/or selective non-catalytic reduction APCDs.

[8] Part 75 requires the use of substitute data when a monitor is not working properly or has not been quality assured. If the monitor is reporting valid emission data for less than 80 percent of operating hours during the previous 8,760 hours (i.e., one year), substitute data equal to the maximum potential concentration or maximum potential flow are applied for any missing data or invalid data. This "conservative" emission value is intended to ensure emissions are not underreported and to create an incentive for EGUs to properly operate, maintain, and quality assure their monitoring equipment and provide the most accurate and reliable results. See http://www.epa.gov/airmarkets/emissions/continuous-factsheet.html

For purposes of conducting this analysis, we defined a startup event as the initiation of fossil fuel combustion following one or more hours of non-operation (i.e., no combustion), which is consistent with the final definition of startup in the MATS reconsideration rule. For each startup event, we calculated the following values:

- Number of non-operating hours prior to the startup event (i.e., hours between previous cessation of combustion and start of combustion).
- Number of hours between start of combustion and start of electricity generation.[9]
- Gross electricity generation as a percent of nameplate capacity for each hour following start of electricity generation.
- Emission rates and heat input for each hour after start of combustion and start of electricity generation.

For the best performing 12 percent of EGUs, 2-hour rolling average emission rates (pounds per million British thermal units, lb/MMBtu) were calculated following the start of generation. A 2-hour average was used to smooth out some of the variability inherent during startup

4. Results

During calendar years 2011 and 2012, there were 9,719 distinct startup events (see Table 1)[10] – 9,467 at PC EGUs and 252 at CFB EGUs.

Table 1: Number of normal and failed starts by boiler and APCD types, years 2011 and 2012.

Boiler-control	Normal starts	Failed starts	Total starts
PC EGU	**7,364**	**2,103**	**9,467**
Supercritical w/ FGD	*1,612*	*369*	*1,981*
Supercritical w/ SCR	*1,413*	*324*	*1,737*
Subcritical w/ FGD	*4,827*	*1,335*	*6,162*
Subcritical w/ SCR	*2,578*	*823*	*3,401*
CFB EGU	**208**	**44**	**252**

The average EGU had between 9 and 10 startup events per year during 2011 – 2012, but data from a small number of EGUs indicated significantly more startup events (e.g., the EGUs with the most startup events had over 100 startup events in 2011 and over 80 in 2012.) For the 414 coal-fired EGUs in this analysis, the overall number of startup events remains reasonably consistent across both years.

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[9] Reporting instructions for Part 75 allow the use of default megawatt values, typically 1 or 2 MWh, when combustion is underway but gross load is zero. This is typically done for apportioning heat input among EGUs sharing a common stack or pipe. Without the default value, the calculation would require dividing by zero and, therefore, result in an error. For this study, we conservatively set the start of electricity generation from the hour where gross load exceeded 2 MWh.

[10] Because startup events are grouped by boiler and control, a startup event may be counted more than once. For example, each startup event at a PC EGU with an FGD and SCR would be counted as a startup event at an FGD-equipped EGU and at an SCR-equipped EGU.

4.1 Operations between start of combustion and start of generation

We analyzed emissions and operations data for each startup event from the start of fossil fuel combustion to the start of electricity generation. Specifically, we examined the length of time an EGU combusts fossil fuel before initiating electricity generation, giving consideration to the period of time the EGU was offline and whether or not the EGU successfully initiated electricity generation.

Generally, during startup of a coal-fired boiler the operator slowly heats the boiler to avoid problems with boiler expansion and overheating of equipment (e.g., reheaters, superheaters).[11] If the boiler is offline for a short time and does not experience significant temperature declines, the time between start of combustion and start of electricity generation may be very short. Generally, natural gas or fuel oil is combusted during this time to slowly raise the temperature in the boiler. Natural gas and oil are used because of their low ignition temperature and ignition stability.

Approximately 23 percent of the startup events examined in this study failed to generate electricity following the start of fossil fuel combustion. These failed starts can occur for a variety of safety and operating reasons. In general, these failed starts have a short duration – the average failed start combusted fossil fuel, including natural gas, oil, and coal, for less than 8 hours with a median of 4 hours. Figure 1 shows the distribution of hours of fossil fuel combustion during failed starts. Fossil fuel combustion during approximately 75 percent of the failed starts lasted 10 hours or less. The failed starts that combusted fossil fuel for more than 10 hours generally followed longer periods of downtime (e.g., extended maintenance events). The average time offline before such failed starts is approximately 360 hours. Of the 413 EGUs in this study, 91 use complex (i.e., shared) stacks making it difficult to estimate emissions during startup from these EGUs.[12] Of the 319 EGUs with simple (i.e., one stack for one boiler) or multiple stacks (i.e., multiple stacks for one boiler), the total SO_2 emissions during failed starts in 2011 and 2012, combined, were 154 tons of SO_2 and 404 tons of NO_X. This represents less than 0.008 and 0.030 percent of total annual SO_2 and annual NO_X emissions, respectively, at these EGUs.

More than 97 percent of the "normal" starts[13] – a startup event in which an EGU begins combusting fossil fuel and subsequently generating electricity during at least one operating hour before the EGU ceases combusting fossil fuel – in this database were at PC EGUs. Following the start of fossil fuel combustion, PC EGUs began generating electricity in a relatively short period of time. On average, the time between start of fossil fuel combustion and start of generation was less than 9 hours (see Figure 2).

[11] Lefton, S.A., and Hilleman, D., 2011. Make Your Plant Ready for Cycling Operation. Power Magazine. August 1, 2011, in docket ID EPA-HQ-OAR-2009-0234-20380. (http://www.powermag.com/issues/features/Make-Your-Plant-Ready-for-Cycling-Operations_3885.html)

[12] It is difficult to estimate emissions from a single EGU with a shared stack or pipe because these EGUs generally share a single monitoring system.

[13] For the purpose of this analysis, we define a "normal" start as any startup event that results in electricity generation for more than one hour (i.e., not a "failed" start). This may not represent the "average" or "typical" startup event.

Figure 1: Duration of fossil fuel combustion during failed startup events

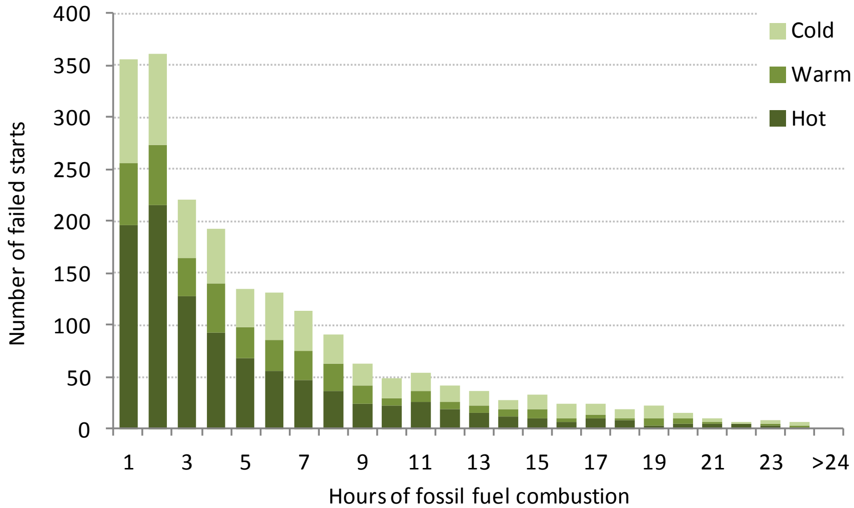
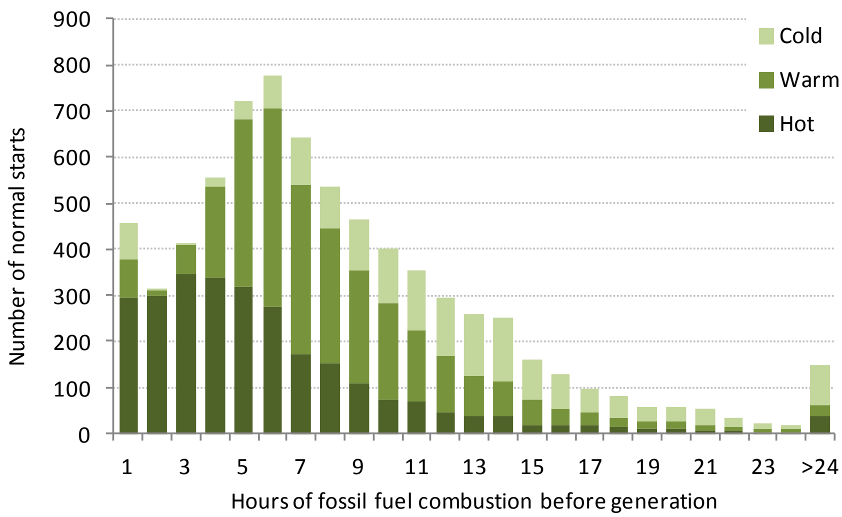


Figure 2: Duration of fossil fuel combustion prior to electricity generation during normal startup events at PC EGUs

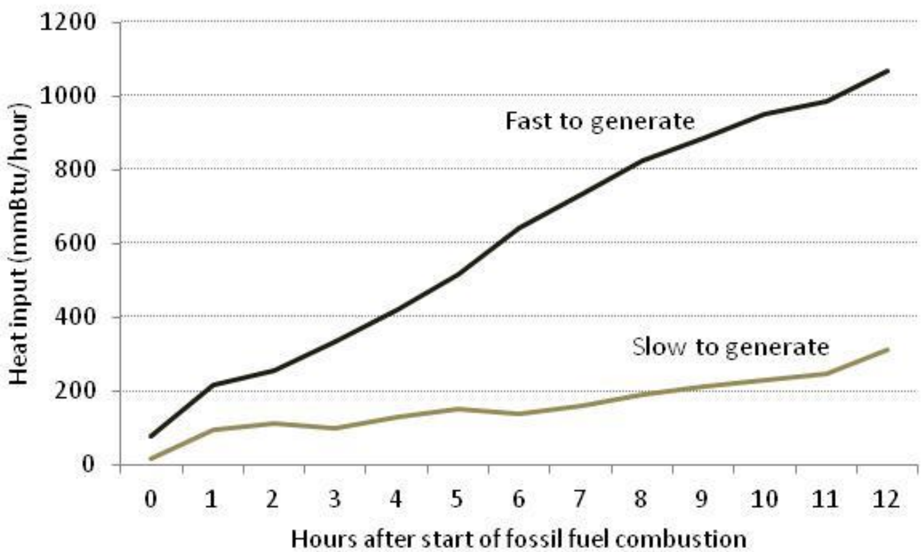


During startup and prior to the start of generation, PC EGUs are generally burning clean fuels (e.g., natural gas, number 2 fuel oil). To estimate the transition from clean fuels to the start of coal combustion, the EPA looked at SO_2 concentration for all startup events, including failed starts, from the initiation of fossil fuel combustion until the SO_2 concentration (parts per million (PPM)) exceeded 10 PPM – a reasonable threshold for the introduction of coal, number 6 fuel oil, or higher-sulfur number 2 oil. On average across both years, it took a little over 9 hours for SO_2 concentrations to exceed 10 PPM, approximately the same length of time it took PC EGUs to start generating electricity.

Approximately 3 percent of the normal startup events in this analysis were at CFB boiler EGUs. For these startup events, the average time between start of fossil fuel combustion and start of generation was approximately 10 hours with a median of 8 hours, comparable to the study population as a whole. However, over 40 percent of startup events at CFB boiler EGUs had extended periods (10 - 75 hours) of fossil fuel combustion before electricity generation commenced. As commenters noted, this may be due to the time it takes to achieve and maintain stability of the “bed.” In general, the hourly heat input during these “slow to generate” startup events (greater than 10 hours between start of fossil fuel combustion and start of electricity generation) is considerably lower than the heat input during “fast to generate” starts (less than or equal to 10 hours between start of fossil fuel combustion and start of electricity generation) (see Figure 3). In other words, if a CFB boiler started electricity generation in 10 hours of less after the start of combustion, total heat input rose quickly. However, if the CFB boiler took a longer time to start electricity generation, the total heat input was lower, on average, and increased at a slower rate.

Prior to the start of generation, CFB EGUs burn clean fuels for several hours. To estimate the transition from clean fuels to the start of coal combustion, the EPA looked at SO_2 concentration for all startup events, including failed starts, from the initiation of fossil fuel combustion until the SO_2 concentration (parts per million (PPM)) exceeded 10 PPM. On average across both years, it took CFB boiler EGUs a little over 5 hours for SO_2 concentrations to exceed 10 PPM.

Figure 3: Heat input per hour following start of fossil fuel combustion at CFB boiler EGUs



4.2 Operations following the start of generation

4.2.1 Pulverized coal EGUs

Following the start of generation, both supercritical and subcritical PC EGUs increased generation rapidly, achieving higher loads within the first few hours. Figure 4 shows that across startup events at supercritical PC EGUs, generation averaged approximately 30 percent of nameplate capacity by hour 3 and approximately 38 percent of nameplate capacity by hour 4. (Note: the yellow line is the average gross load as a percentage of nameplate capacity across all startup events at supercritical PC EGUs; the purple boxes and black whiskers are the quartile ranges.) Figure 5 shows that across startup events at subcritical PC EGUs, generation averaged approximately 33 percent of nameplate capacity by hour 2, 42 percent of nameplate capacity by hour 3, and 49 percent of nameplate capacity by hour 4.

Figure 4: Gross electricity generation as a percentage of nameplate capacity (MW) by hour following start of generation at supercritical PC EGUs

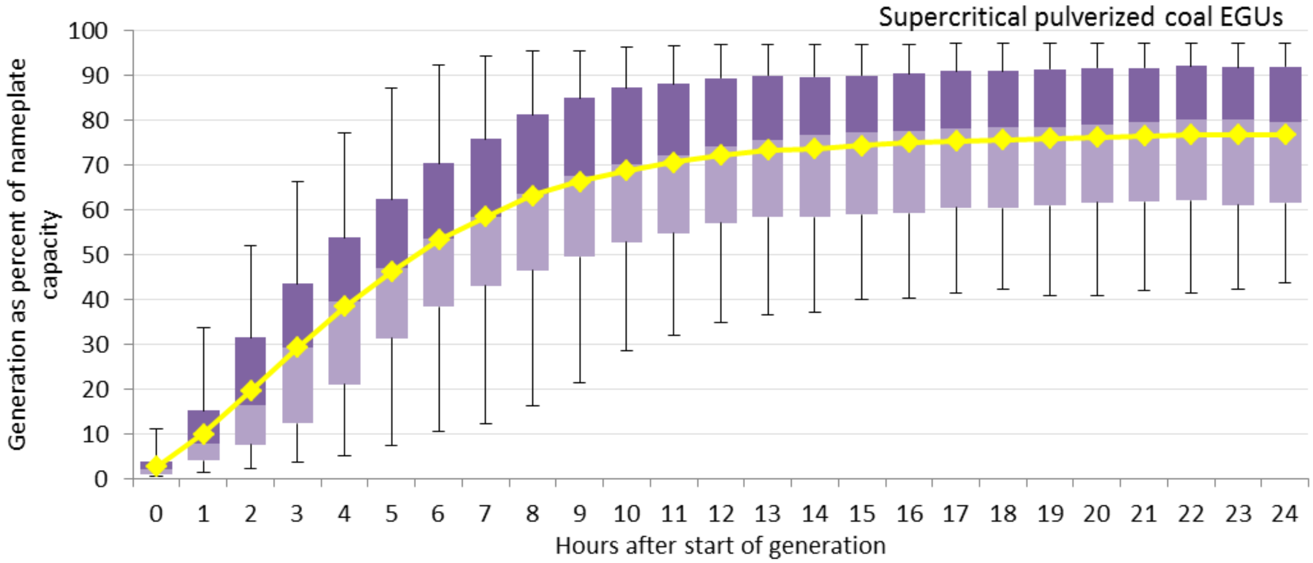
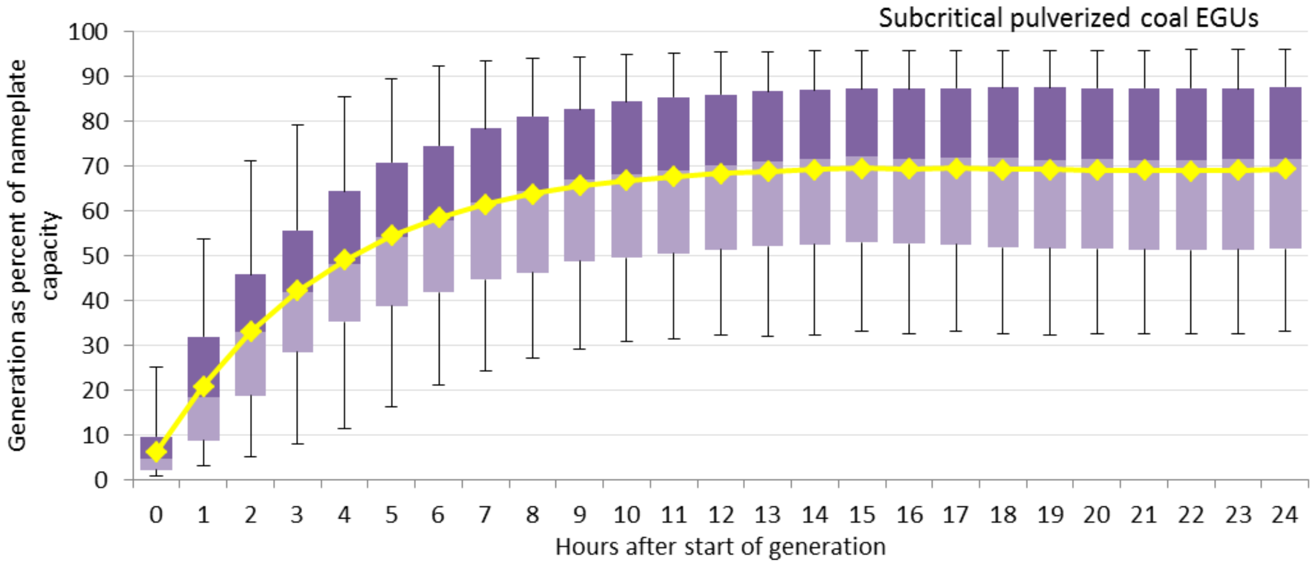


Figure 5: Gross electricity generation as a percentage of nameplate capacity (MW) by hour following start of generation at subcritical PC EGUs



During the majority of normal starts, supercritical (Figure 6) and subcritical (Figure 7) PC EGUs achieved 20 percent and 25 percent of nameplate capacity within the first few hours after the start of generation.

Figure 6: Hours after start of generation for supercritical PC EGUs to generate 20 percent (left) and 25 percent (right) of nameplate capacity

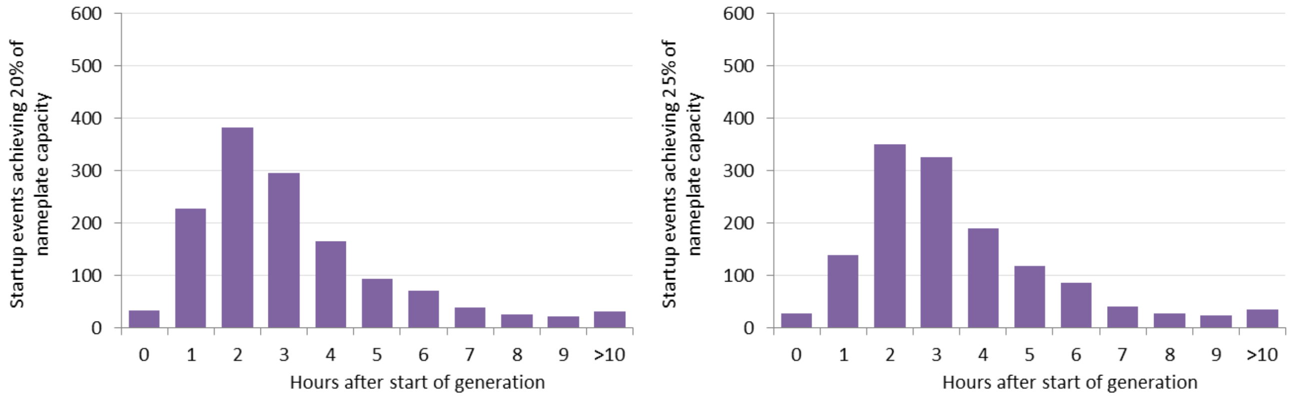
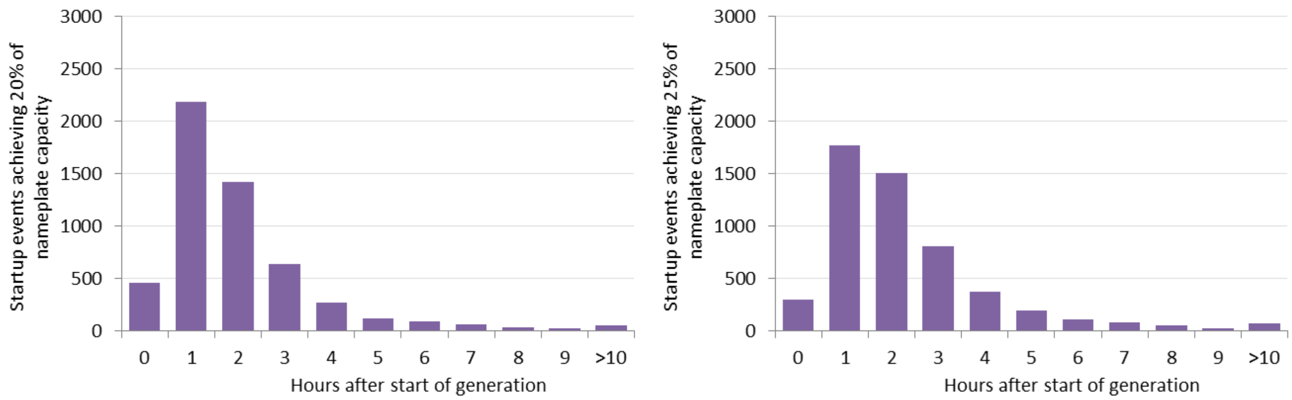


Figure 7: Hours after start of generation for subcritical PC EGUs to generate 20 percent (left) and 25 percent (right) of nameplate capacity



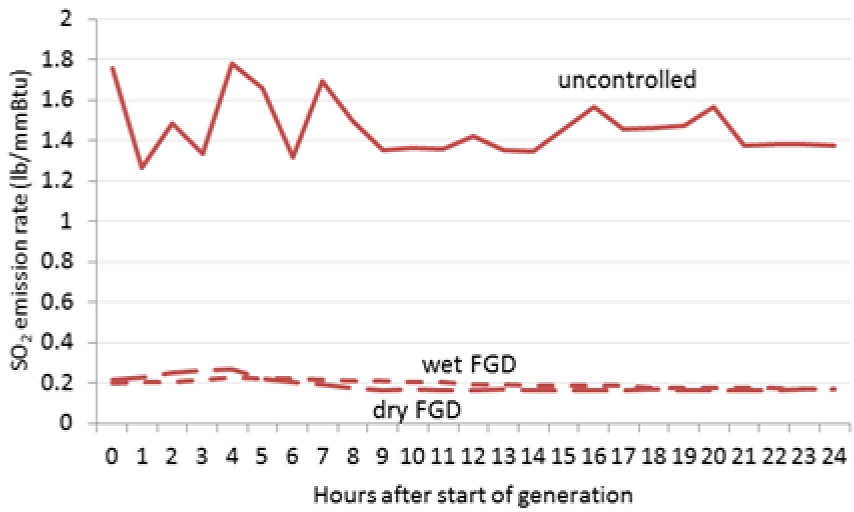
4.2.1.1 SO_2 emissions from supercritical PC EGUs with FGDs

Of the 1,802 normal startup events at supercritical PC EGUs, over 80 percent occurred at EGUs with wet FGD and an additional 6 percent were at EGUs with dry FGD (see Table 2). The average SO_2 emission rates for the hours following the start of generation are shown in Figure 8. The average SO_2 emission rates for normal starts at both dry FGD- and wet FGD-equipped supercritical PC EGUs are approximately 80 - 90 percent lower across every hour (0-24) than the average SO_2 emission rates for normal starts at supercritical PC EGUs without FGDs (i.e., uncontrolled). This indicates that both wet FGD and dry FGD APCDs are capable of operating and capturing SO_2 emissions commensurate with the start of electricity generation.

Table 2: Number of normal starts at supercritical PC EGUs by SO_2 control type

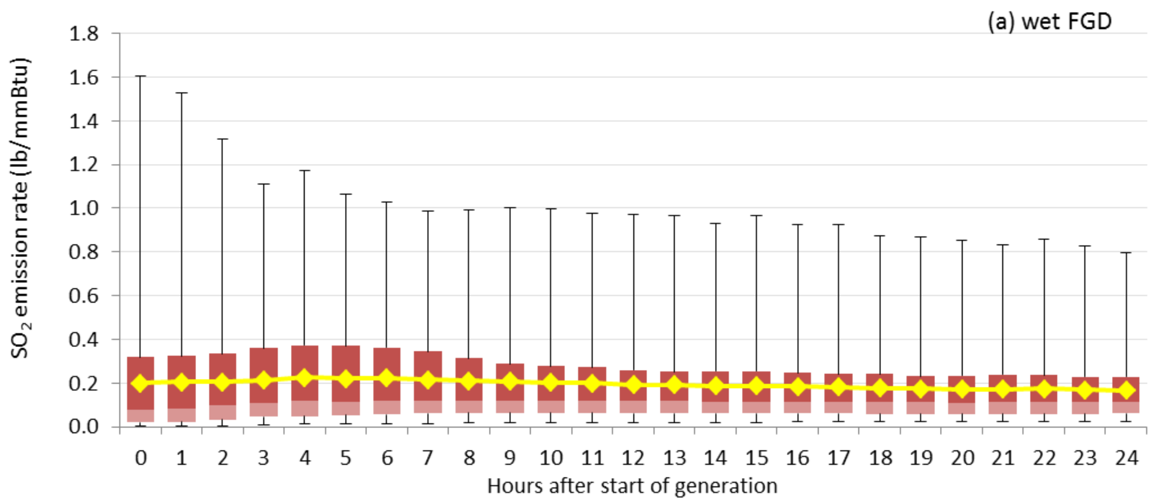
SO_2 control type	Normal starts
Wet FGD	1,492
Dry FGD	120
Uncontrolled for SO_2	190
Total	**1,802**

Figure 8: Average SO_2 emission rates following start of generation at supercritical PC EGUs by SO_2 control type



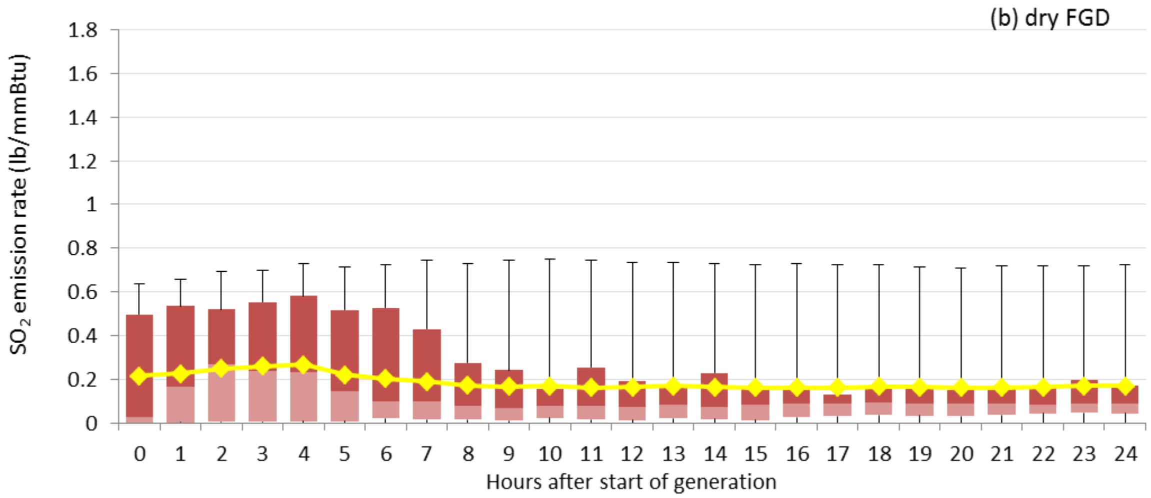
Figures 9 and 10 show the distribution of SO_2 emission rates during normal starts at supercritical PC EGUs with wet FGD (Figure 9) and dry FGD (Figure 10). (Note: the top and bottom 5 percent of emission rates are excluded from the chart;[14] the yellow line is the average emission rate across starts at supercritical PC EGUs with FGD; the red boxes and black whiskers are the quartile ranges.) The figures show that average and median SO_2 emission rates are low at the start of generation for the majority of normal starts, indicating that both wet FGD and dry FGD are likely operating at the start of generation.

Figure 9: Average SO_2 emission rates following start of generation at supercritical PC EGUs with wet FGDs



[14] A number of PC EGUs shut down in 2011 and 2012. Several startup events at these EGUs had high SO_2 emissions for more than 24 hours after the start of generation indicating the FGD equipment was likely not in use. By excluding the top 5 percent of values, these outliers do not bias the analysis. For parity, we also excluded the bottom 5 percent.

Figure 10: Average SO_2 emission rates following start of generation at supercritical PC EGUs with dry FGDs



Following gross load levels greater than or equal to 25 percent of nameplate capacity, supercritical PC EGUs' SO_2 emission rates are relatively low and stable (see Figure 11 for wet FGD and Figure 12 for dry FGD). Both types of FGDs show declining average SO_2 emission rates by the third hour after reaching 25 percent load.

Figure 11: Average SO_2 emission rates following gross load levels greater than or equal to 25 percent of nameplate capacity at supercritical PC EGUs with wet FGDs

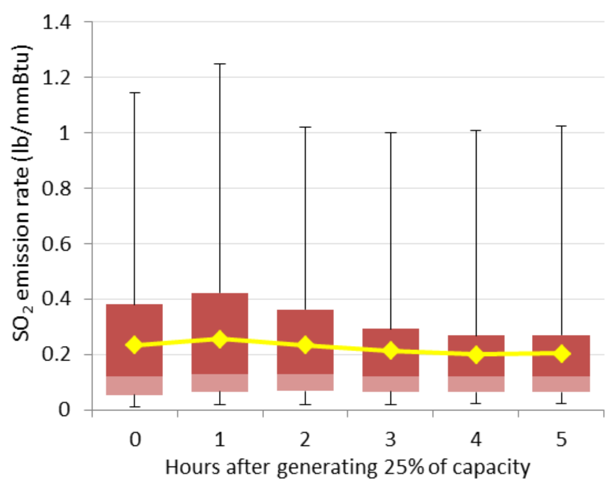
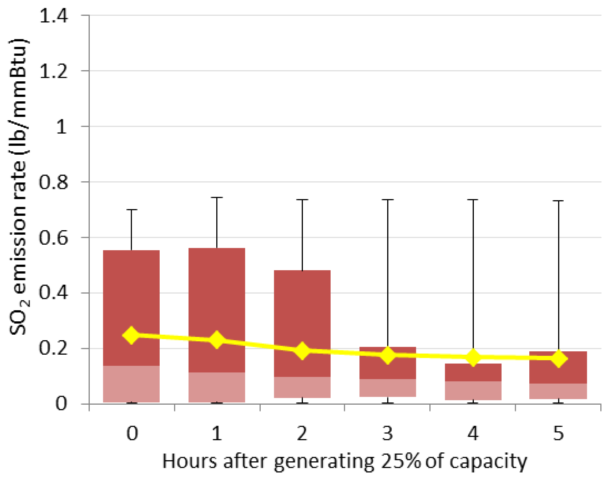


Figure 12: Average SO_2 emission rates following gross load levels greater than or equal to 25 percent of nameplate capacity at supercritical PC EGUs with dry FGDs



4.2.1.2 NO_X emissions from supercritical PC EGUs with SCRs

To determine the time necessary to start SCRs, the EPA examined hourly NO_X emissions at EGUs with and without SCR. Of the 1,802 normal startup events at supercritical PC EGUs, 78 percent were at supercritical PC EGUs with SCR (see Table 3). Nearly all of the remaining non-SCR supercritical PC EGUs have low-NO_X burners, over-fire air, and/or selective non-catalytic reduction installed. The average NO_X emission rates for the hours following the start of generation are shown in Figure 13. The average NO_X emission rates for SCR-equipped and non-SCR supercritical PC EGUs begin at approximately the same level but the rate for the SCR-equipped EGUs grows slower and begins to decline by hour 5. This indicates that, on average, SCR APCDs are able to begin controlling NO_X emissions within 4 to 6 hours following the start of electricity generation at supercritical PC EGUs.

Table 3: Number of normal starts at supercritical PC EGUs by NO_X control type

NO_X control type	**Normal starts**
SCR	1,413
non-SCR	389
Total	**1,802**

Figure 13: Average NO_X emission rates following start of generation at supercritical PC EGUs by NO_X control type

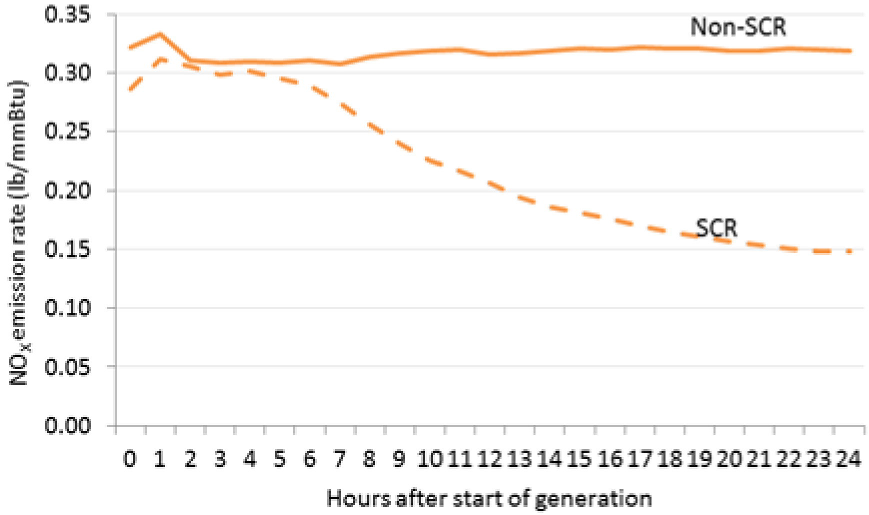


Figure 14 shows the distribution of NO_X emission rates during normal starts at supercritical PC EGUs with SCR NO_X APCDs. (Note: the top and bottom 5 percent of emission rates are excluded from the chart; the yellow line is the average emission rate across starts at PC EGUs with SCR; the orange boxes and black whiskers are the quartile ranges.) The figure shows that average and median NO_X emission rates for the full range of normal starts at SCR-equipped supercritical PC EGUs begin to decline around hour 6, indicating that, on average, SCR effectively controls NO_X approximately 6 hours or less after the start of generation.

Figure 14: Average NO_X emission rates following start of generation at supercritical PC EGUs

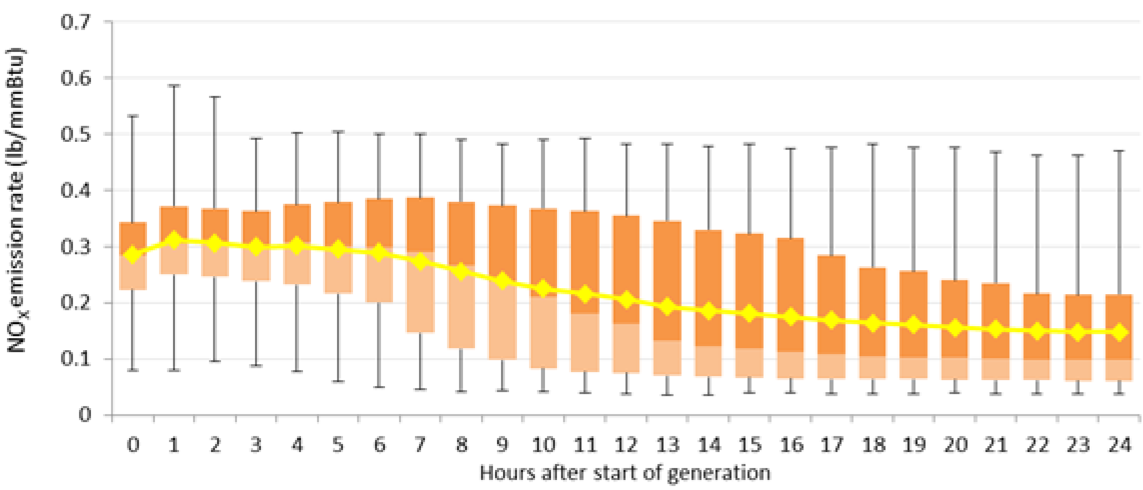
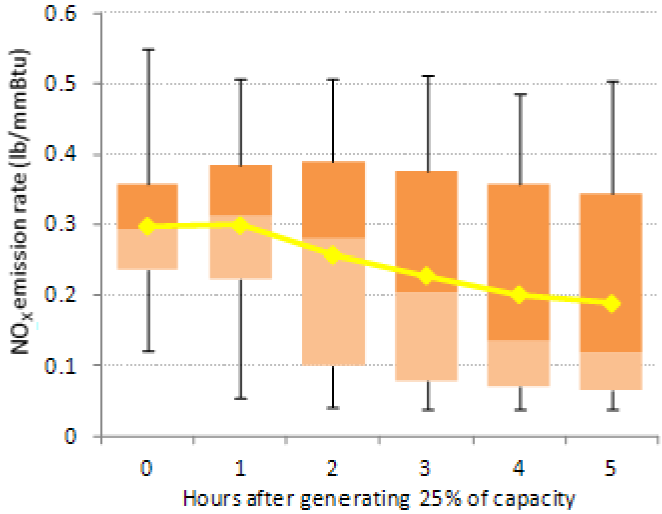


Figure 15 shows the distribution of NO_X emission rates during normal starts after achieving 25 percent of nameplate capacity at supercritical PC EGUs with SCR NO_X APCDs. (Note: the top and bottom 5 percent of emission rates are excluded from the chart; the yellow line is the average emission rate across starts at supercritical PC EGUs with SCR; the orange boxes and black whiskers are the quartile ranges.) The figure shows that average and median NO_X emission rates at SCR-equipped supercritical PC EGUs begin to decline around 2 hours after achieving 25 percent of nameplate electricity generating capacity.

Figure 15: Average NO_X emission rates following gross load levels greater than or equal to 25 percent of nameplate capacity at supercritical PC EGUs with SCRs



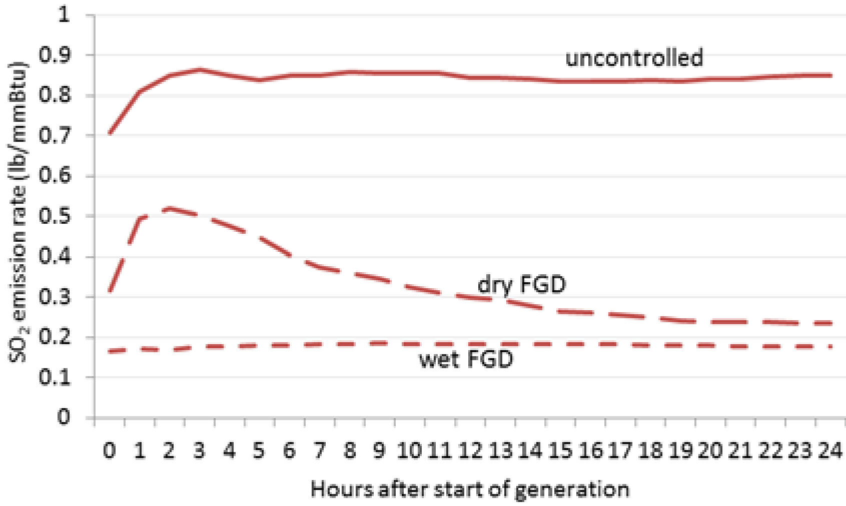
4.2.1.3 SO_2 emissions from subcritical PC EGUs with FGDs

Of the 5,770 normal startup events at subcritical PC EGUs, 70 percent were at subcritical PC EGUs with wet FGD and an additional 14 percent were at subcritical PC EGUs with dry FGD (see Table 4). The average SO_2 emission rates for the hours following the start of generation are shown in Figure 16. The average SO_2 emission rates for normal starts at wet FGD-equipped subcritical PC EGUs are approximately 75 - 80 percent lower across every hour (0-24) than the average SO_2 emission rates for normal starts at subcritical PC EGUs without FGDs (i.e., uncontrolled). The average SO_2 emission rates for normal starts at dry FGD-equipped subcritical PC EGUs are approximately 40 - 70 percent lower across every hour (0-24) than the average SO_2 emission rates for normal starts at subcritical PC EGUs without FGDs.

Table 4: Number of normal starts at subcritical PC EGUs by SO_2 control type

SO_2 control type	**Normal starts**
Wet FGD	4,024
Dry FGD	803
Uncontrolled for SO_2	943
Total	**5,770**

Figure 16: Average SO_2 emission rates following start of generation at subcritical PC EGUs by SO_2 control type



Figures 17 and 18 show the distribution of SO_2 emission rates during normal starts at subcritical PC EGUs with wet FGD (17) and dry FGD (18). (Note: the top and bottom 5 percent of emission rates are excluded from the chart; the yellow line is the average emission rate across starts at subcritical PC EGUs with FGD; the red boxes and black whiskers are the quartile ranges.) The figures show that average and median SO_2 emission rates are low at the start of generation for the majority of normal starts, indicating that wet FGD are likely operating at the start of electricity generation and dry FGD begin controlling emissions within the first 3 to 4 hours after the start of electricity generation.

Figure 17: Average SO_2 emission rates following start of generation at subcritical PC EGUs with wet FGDs

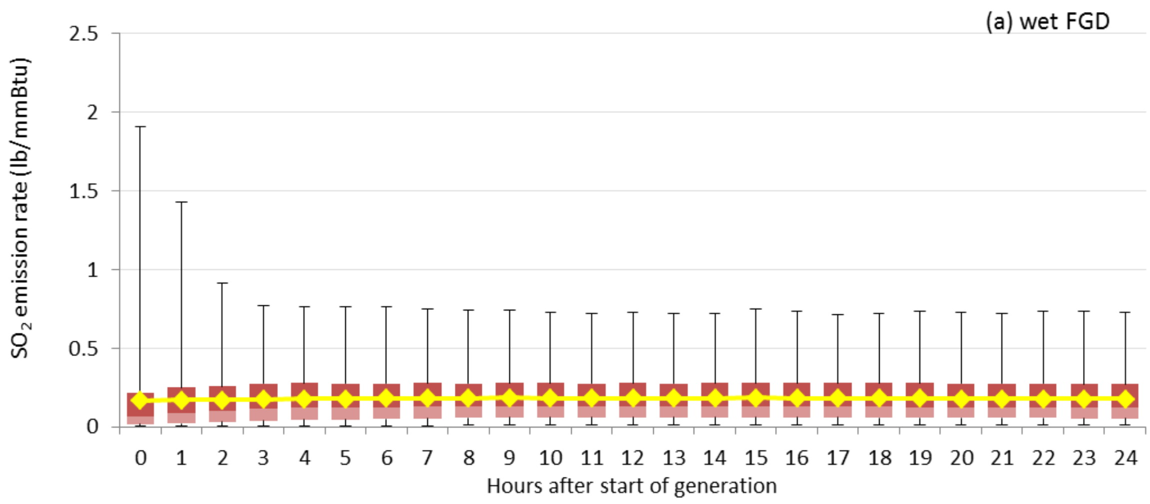
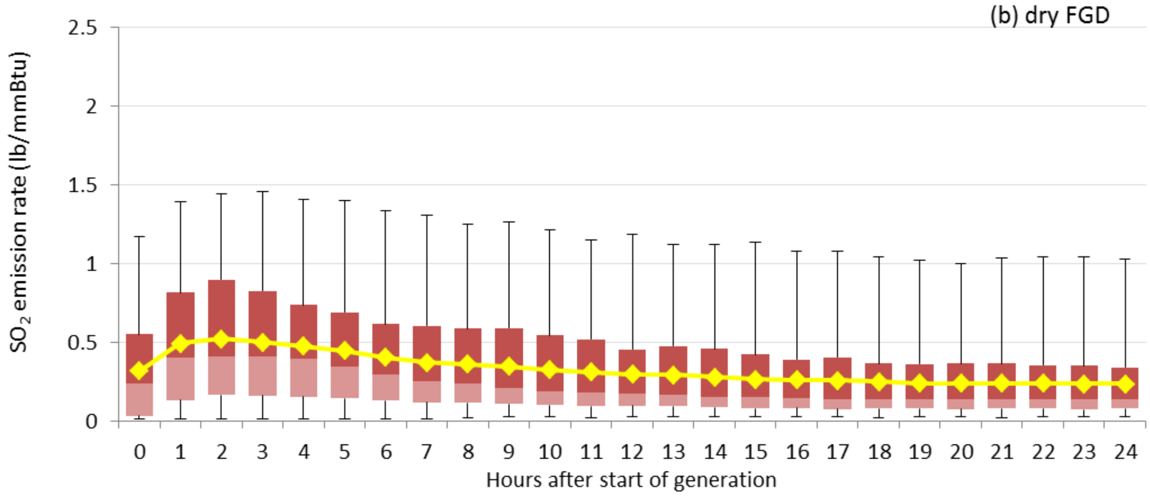


Figure 18: Average SO_2 emission rates following start of generation at subcritical PC EGUs with dry FGDs



Following gross load levels greater than or equal to 25 percent of nameplate capacity, subcritical PC EGUs with wet FGD have relatively low and stable average and median SO_2 emission rates (see Figure 19) while subcritical PC EGUs with dry FGD reduce average SO_2 emission rates (see Figure 20) by over 30 percent in the first 3 hours following gross load levels of 25 percent of nameplate capacity. Average and median SO_2 emission rates at dry FGD-equipped subcritical PC EGUs begin declining within the first hour of achieving gross load equal to or greater than 25 percent of nameplate capacity.

Figure 19: Average SO_2 emission rates following gross load levels greater than or equal to 25 percent of nameplate capacity at subcritical PC EGUs with wet FGDs

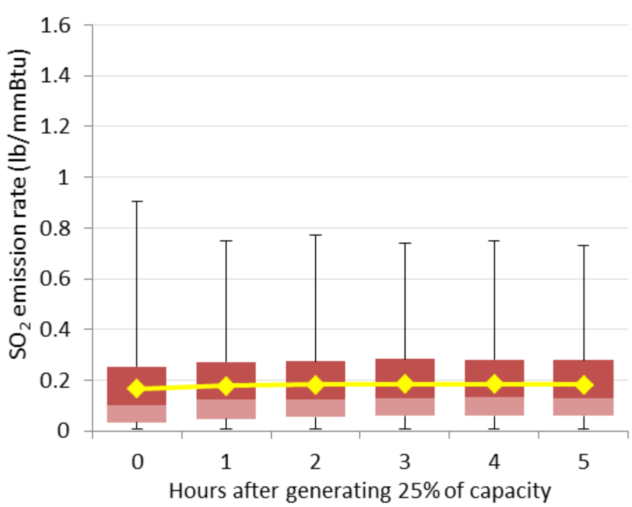
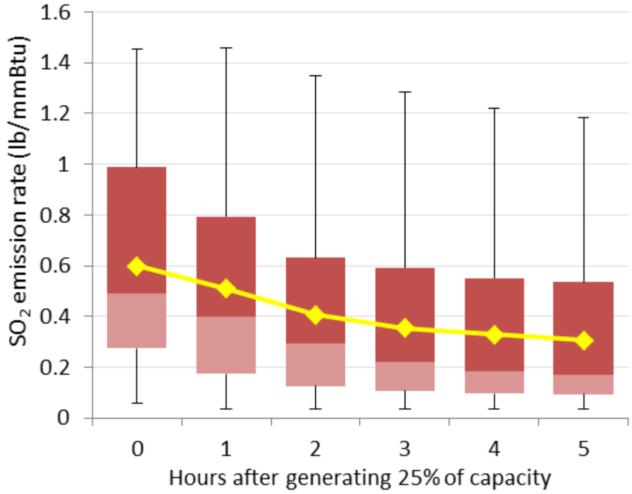


Figure 20: Average SO_2 emission rates following gross load levels greater than or equal to 25 percent of nameplate capacity at subcritical PC EGUs with dry FGDs



4.2.1.4 NO_X emissions from subcritical PC EGUs with SCRs

Of the 5,770 normal startup events at subcritical PC EGUs, nearly 47 percent were at subcritical PC EGUs with SCR (see Table 5). Nearly all of the remaining non-SCR subcritical PC EGUs have installed low-NO_X burners, over-fired air, and/or selective non-catalytic reduction. The average NO_X emission rates for the hours following the start of generation are shown in Figure 21. The average NO_X emission rates for SCR-equipped and non-SCR subcritical PC EGUs begin at approximately the same level but the rate for the SCR-equipped EGUs begins to decline around hour 2.

Table 5: Number of normal starts at subcritical PC EGUs by NO_x control type

NO_X control type	Normal starts
SCR	2,578
non-SCR	3,192
Total	**5,770**

Figure 21: Average NO_X emission rates following start of generation at subcritical PC EGUs by NO_X control type

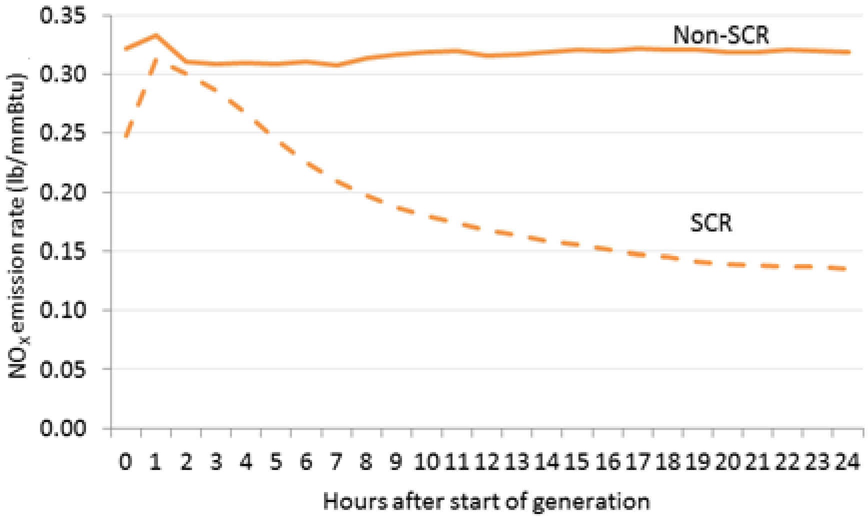
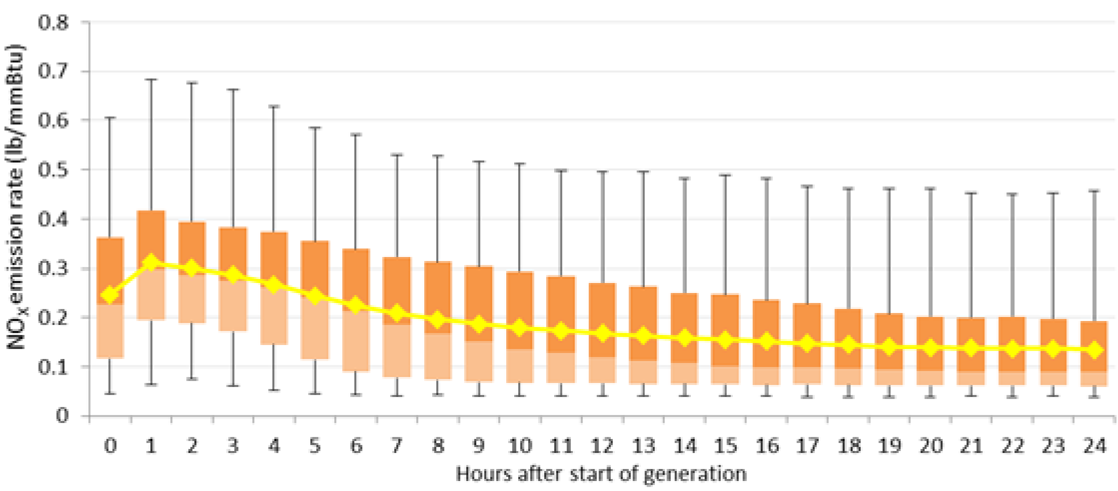


Figure 22 shows the distribution of NO_X emission rates during normal starts at subcritical PC EGUs with SCR NO_X APCDs. (Note: the top and bottom 5 percent of emission rates are excluded from the chart; the yellow line is the average emission rate across starts at PC EGUs with SCR; the orange boxes and black whiskers are the quartile ranges.) The figure shows that average and median NO_X emission rates for the full range of normal starts at SCR-equipped subcritical PC EGUs begin to decline around hour 2, indicating that SCR are likely starting to control NO_X 2 to 3 hours after the start of generation.

Figure 22: Average NO_X emission rates following start of generation at subcritical PC EGUs

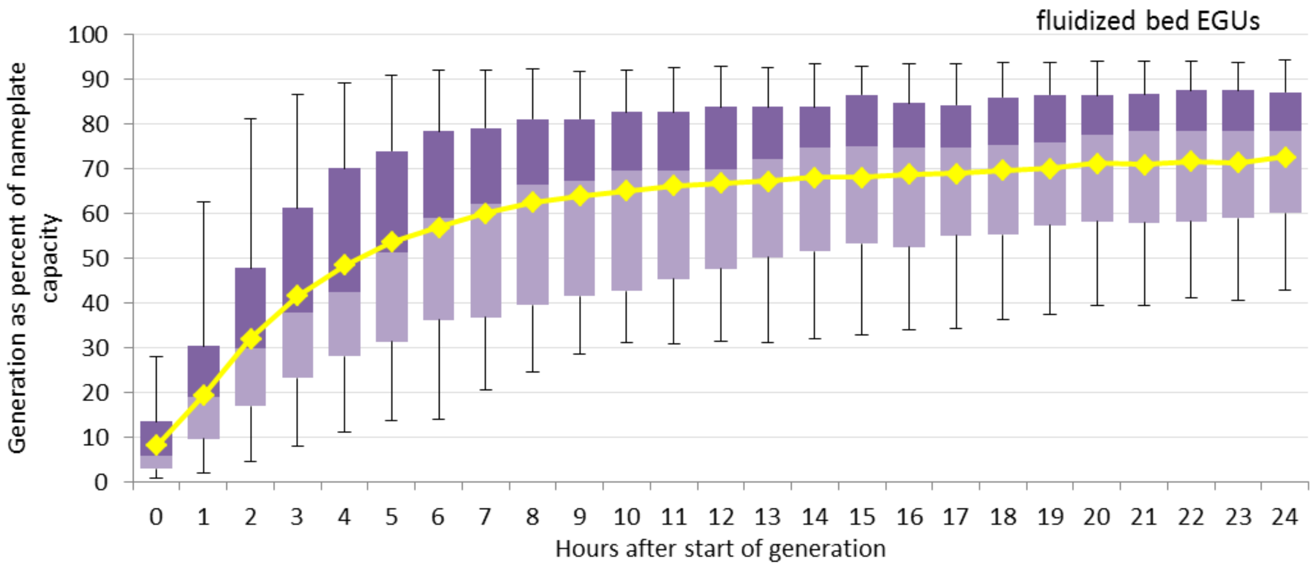


4.2.2 Circulating fluidized bed boiler EGUs

CFB boiler EGUs typically do not have post-combustion FGD APCDs installed since they achieve significant SO_2 capture by adding lime or limestone to the bed of the boiler. For this reason, the EPA evaluated CFB boiler EGU starts separately from PC EGUs.

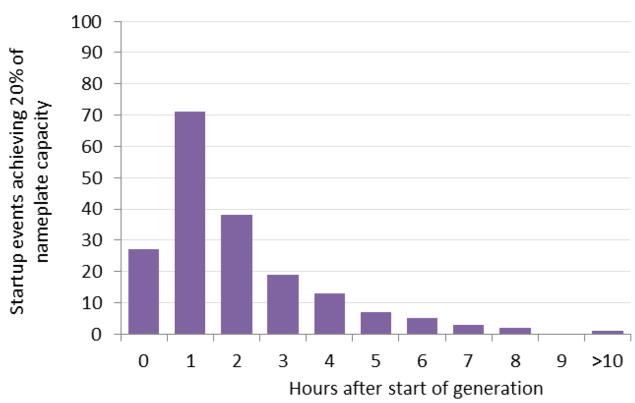
Figure 23 shows that across startup events at CFB boiler EGUs, generation averaged approximately 30 percent of nameplate capacity by hour 2 and 40 percent of nameplate capacity by hour 3. (Note: the yellow line is the average gross load as a percentage of nameplate capacity across all startup events at CFB boiler EGUs; the purple boxes and black whiskers are the quartile ranges.) We found that CFBs achieve 25 percent and 40 percent load bins, on average, as fast as subcritical and supercritical PC EGUs (see Figures 4 and 5).

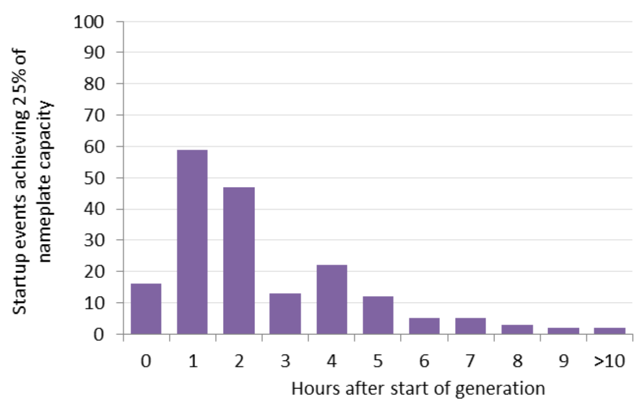
Figure 23: Gross electricity generation as a percentage of nameplate capacity (MW) by hour following start of generation at CFB boiler EGUs



During the majority of normal startup events, CFB boiler EGUs achieved 20 percent and 25 percent of nameplate capacity within the first few hours following the start of electricity generation (see Figure 24).

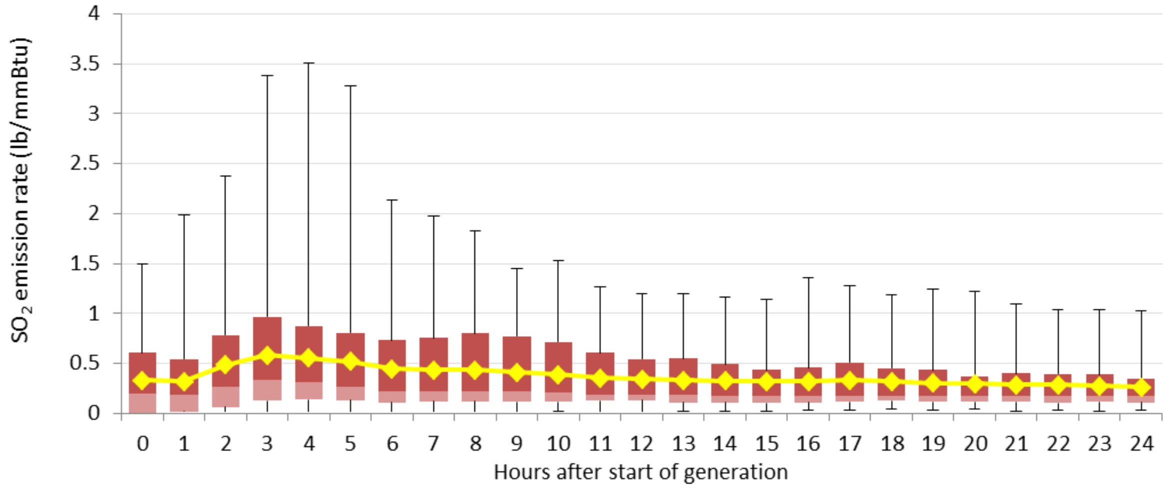
Figure 24: Hours after start of generation for CFB boiler EGUs to generate 20 percent (left) and 25 percent (right) of nameplate capacity





Because CFB boiler EGUs generally do not have separate FGD APCDs, there is no need to compare uncontrolled and controlled emission rates. Figure 25 shows that average and median SO_2 emission rates during startup events at CFB boiler EGUs begin to decline at hours 4 to 6 following the start of electricity generation. (Note: the top and bottom 5 percent of emission rates are excluded from the chart; the yellow line is the average emission rate across startup events at CFB boiler EGUs with FGD; the red boxes and black whiskers are the quartile ranges.)

Figure 25: Average SO_2 emission rates following start of generation at CFB boiler EGUs



5. Average of the best performing 12 percent of existing EGUs

CAA section 112 requires the EPA to establish standards based on the average of the best performing 12 percent of EGUs. To evaluate the startup time of the best performing 12 percent (i.e., the EGUs that were able to start operation of APCDs in the shortest time) – the EPA refined the dataset and established a two-tier test to identify when controls started operation. First, startup events in which electricity generation lasted less than 4 hours before fossil fuel combustion ended were deleted from the dataset. This removed 563 startup events. For the remaining 6,963 startup events, the EPA calculated the 2-hour rolling average emission rate (lb/MMBtu). A 2-hour average was used to smooth out some of the variability inherent during startup. These 2-hour rolling averages were then subjected to two tests to determine when the controls were operational:

- Following the 2-hour average maximum emission rate, at what 2-hour averaging period does the emission rate decline by a predetermined threshold and stay below that threshold?
- At what 2-hour averaging period does the 2-hour average emission rate fall and remain below 110 percent of an EGU's annual average emission rate? If the rate is lower than 110 percent of the annual average emission rate, the control is assumed to be operational beginning in that 2-hour averaging period. This test is particularly relevant for controls that initiate operation before the start of generation.

Calculating the time it took the best performing 12 percent of EGUs to meet one of these two tests required several calculations:

1. For each normal startup event, we identified the time (i.e., the 2 hour average) at which the EGU met one or both of the tests listed above. Startup events for SO_2 and NO_X APCDs were analyzed separately.
2. For each EGU, we averaged the time identified in step 1 for all the EGU's startup events in 2011 and 2012. This provided an average time (i.e., 2 hour average) for the EGU to initiate operation of APCDs

3. We ranked EGUs by the average time to initiate operation of SO_2 APCDs and NO_X APCDs to identify the best performing 12 percent (i.e., the EGUs that had the lowest average time to initiate APCD operation).
4. Finally, we averaged the best performing 12 percent of EGUs' average time to initiate operation of SO_2 APCDs and NO_X APCDs to calculate the end result.

Tables 6 and 7 show the results of the analysis with these two tests – percent reduction threshold and 110 percent of annual average rate – for SO_2 and NO_X controls, respectively. The time to "controls on" varies for different percent reduction thresholds, ranging from approximately 3.0 to 4.5 hours.

Table 6: Average number of hours until SO_2 "controls on" for best performing 12 percent of EGUs

Emission decline threshold	Avg hours to "controls on" for top 12%	Slope for all hours following "controls on" (95% CI)
10%	3.15 hours	-3.88% (±2.4)
15%	3.51 hours	-3.73% (±2.4)
20%	3.86 hours	-3.62% (±2.4)
25%	4.20 hours	-3.82% (±2.6)
30%	4.53 hours	-3.04% (±2.6)

Table 7: Average number of hours until NO_X "controls on" for best performing 12 percent of EGUs

Emission decline threshold	Avg hours to "controls on" for top 12%	Slope for all hours following "controls on" (95% CI)
10%	3.33 hours	-10.35% (±0.8)
15%	3.60 hours	-10.04% (±1.2)
20%	3.90 hours	-7.70% (±2.2)
25%	4.08 hours	-7.34% (±1.5)
30%	4.57 hours	-6.06% (±1.6)

Using an emission decline threshold of 20 percent, the results indicate that the average of the best performing 12 percent of EGUs initiate SO_2 and NO_X control within 4 hours after the start of electricity generation (see Figure 26). At this threshold, the EGUs that comprise the best performing 12 percent include a CFB, supercritical and subcritical pulverized coal boilers, and wet and dry FGD-equipped EGUs (see Table 8).

Table 8: Number of EGUs in best performing 12 percent with different characteristics

Characteristic	SO_2 "top 12%"	NO_X "top 12%"
Supercritical	10	9
Subcritical	33	18
Wet FGD	31	NA
Dry FGD	12	NA
CFB	1	NA

6. Conclusion

In this analysis of supercritical and subcritical PC EGUs with FGD and/or SCR and CFB boiler EGUs, the EPA examined several indicators that can aid in assessing the time required to achieve operating benchmarks. These indicators show that, on average, all types of EGUs in this study:

- can reach 25 percent of nameplate capacity in 3 hours or less after the start of generation;
- can begin controlling SO_2 and NO_X emissions 3 hours or less after reaching 25 percent of nameplate capacity or 6 hours or less following the start of electricity generation.

Evaluating the best performing 12 percent of EGUs, this analysis shows these EGUs, on average:

- can achieve and maintain a 20 percent reduction below the maximum emission rate or maintain an emission rate below 110 percent of the EGU's annual emission rate in 4 hours or less following the start of generation.
- The best performing 12 percent of EGUs include CFB, and supercritical and subcritical PC EGUs.

We found no significant difference in performance related to startup events between the different boiler types and APCD technologies assessed in this analysis.