

Important Information Concerning the Menu of Control Measures

The U.S. EPA compiled this Menu of Control Measures (MCM) to provide information useful for: (1) developing local emission reduction and NAAQS SIP scenarios, and (2) identifying and evaluating potential control measures. It is intended to provide a broad, though not comprehensive, listing of potential emissions reduction measures for direct PM_{2.5} and precursors of ozone and PM_{2.5} (NO_x, VOC, SO₂, and ammonia). The MCM is based on data found in reports from the U.S. EPA and several other organizations, such as other Federal agencies, multi-state organizations, state air agencies, and contractor reports.

While mobile source control measures are not included in the MCM, we encourage State air planning agencies to consider such measures when they conduct an initial screening step to identify the sectors that warrant more detailed analysis as part of their control strategy preparation for nonattainment ozone or PM SIPs. SIPs should incorporate information from mobile source emissions modeling runs for States' specific geographic areas according to guidance from EPA's Office of Transportation and Air Quality (OTAQ). Please contact your EPA Regional Offices and the State Measures and Transportation Planning Center in OTAQ for information on possible mobile source control measures. Additional information can also be found at the State and Local Transportation Resources website at <https://www.epa.gov/state-and-local-transportation>.

Before examining potential control measures for a particular area, an important step is to identify the nature of the PM_{2.5} or ozone problem in the area, including the key source sectors contributing to the problem. The severity, nature and sources of the problem vary from area to area, so the measures that will be most efficient at reducing emissions and cost-effective will also vary by area. The geographic area in which emission reduction measures are effectively applied will vary depending on the extent to which pollution sources outside the area contribute to an area's air quality problem. Similarly, the costs of applying a given control measure will be case-specific. While the MCM provides national-level average control costs and control efficiency estimates derived from relevant references, there is inherent uncertainty in the estimates. We do not attempt to provide rigorous treatment of these uncertainties, but rather provide the control efficiency and cost estimates as a rough "ballpark" starting point. The MCM also does not provide specific emissions monitoring and testing information. We encourage the use of source-specific assessments for these activities because such assessments will be more reliable.

The MCM contains several tabular lists of point source and non-point source control measures, organized by pollutant, i.e., NO_x, VOC, PM, ammonia, and SO₂. The tables include a control measure abbreviation - the first letter is the primary pollutant associated with the measure, and the additional letters can identify the control technology, the type of emissions unit, and the fuel used in the emissions unit. The tables also identify reference sources that the user may wish to consult for more information. Note that this technical document is focused on identification of measures and does not address mechanisms for implementation, such as whether a measure would be implemented on a mandatory or voluntary basis.

Users of this information may want to consider local cost factors for more refined analyses. While the MCM presents the average control cost per ton of emissions removed, some of the measures in the MCM have equations in the Control Measure Database that allow for more precise estimates of costs if required information about the source (e.g., design capacity, stack flow rate) is available. Nonetheless, any estimates calculated using either the average cost per ton or related equation will not be as precise as a rigorous engineering assessment that explicitly considers local and site-specific cost factors.

Information about the Control Strategy Tool and related Control Measure Database can be found at <https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-analysis-modelstools-air-pollution>, while the EPA Air Pollution Control Cost Manual often used in engineering assessments can be found at <https://www.epa.gov/economic-and-cost-analysis-air-pollution-regulations/cost-reports-and-guidance-air-pollution>.

In many cases the accuracy of the MCM cost and control efficiency information is limited by the information in the emissions inventory to which it is applied. For example, for a more reliable estimate, it is important to know what control measures or technologies are currently in place at a source before quantifying the cost and increased control efficiency of a more effective control measure. Information on existing control measures and technologies in place at specific sources is often limited in emissions inventories.

We expect to make ongoing revisions to the measures in this document as we receive additional information, and as new control measures become available. We invite users to provide suggestions for additional measures, or additional sources of information on measures, that they believe should be included in this document.

Feedback is welcome and encouraged - please send comments by clicking the "Contact Us" link on <https://www.epa.gov/air-quality-implementation-plans/menu-control-measures-naaqs-implementation>.

Point & NonPoint NH3
Menu of Control Measures
Updated 9/22/2022

Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
Agricultural Ammonia	Cattle Feedlots	ACHMADDBFL	Chemical Additives to Waste	50	\$330		This control is the adding of chemicals to cattle waste to reduce ammonia emissions from cattle feedlots.	Pechan 2006, Axe 1999x, McCubbin et al. 2002
Agricultural Ammonia	Poultry Operations	ACHMADDCHK	Chemical Additives to Waste	75	\$1,466		This control is the chemical addition of alum to poultry litter. Alum is used to stabilize poultry litter to reduce ammonia emissions. Alum, an acid-forming compounds, keeps the pH of the poultry litter below 7, which inhibits ammonia volatilization. The control effectiveness for alum treatment is estimated to be 75 percent (Moore 1999x). The control effectiveness is highest during the early part of the growing cycle (i.e., >95 percent), when the young chickens are most susceptible to health problems from high ammonia levels. The control effectiveness drops off during the grow-out (about two months). Alum is then reapplied to the litter before the next grow-out begins (typically, there are 5 or 6 grow-outs per year). There is assumed to be 100 percent penetration.	Pechan 2006, Axe 1999x, Moore 1999x, McCubbin et al. 2002
Agricultural Ammonia	Hog Operations	ACHMADDHOG	Chemical Additives to Waste	50	\$106		This control is the adding of chemicals to hog waste to reduce ammonia emissions from hog feedlots. Assessment of control measures applicable to ammonia emissions for hog operations is based on procedures used for cattle operations. There is assumed to be 100 percent penetration; however, the modeling parameters are probably most applicable to large hog farming operations. Hence, it may be more reasonable to apply the control in counties with large hog raising operations (i.e., using COA data).	Pechan 2006, Axe 1999x, McCubbin et al. 2002
Agricultural Ammonia	Dairy Operations	AEMRGDIARY	Emergent Control	55	\$14,459		This control consists of a composite of the following: solids separations/nutrient removal systems, a phototrophic lagoon processing system, a liquid manure injection and spreading system, and a man-made wetlands system for nitrogen removal. The control efficiency and costs used in CoST area an average across all of these control technologies.	EPA 2006e
Agricultural Ammonia	Hog Operations	AEMRGHOG	Emergent Control	70	\$14,459		This control is a solids separation-tangential flow separator combined with a fan separation system. The system treats swine waste from finishing barns. Manure flushed from the barns flows first to a collection pit, then to an above-ground feed tank, then to the fan separator which is on a raised platform.	EPA 2006e

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NonEGU Point	Lean Burn ICE - NG	NAFRICENG	Air to Fuel Ratio Controller	20	NOX < 365 tpy: \$1,121		This control is the use of air/fuel ratio adjustment to reduce NOx emissions. This control applies to gasoline powered internal combustion engines with uncontrolled NOx emissions greater than 10 tons per year.	CARB 2001, EPA 2018, RTI 2014
NonEGU Point	Internal Combustion Engines - Gas	NAFRICGS	Adjust Air to Fuel Ratio	20	NOX < 365 tpy: \$2,723 NOX > 365 tpy: \$659		This control is the use of air/fuel ratio adjustment to reduce NOx emissions. This control applies to natural gas-fired internal combustion engines with uncontrolled NOx emissions greater than 10 tons per year.	EPA 1993c, Pechan 1998a, Pechan 2006
NonEGU Point	Internal Combustion Engines - Gas	NAFRICGS	Adjust Air to Fuel Ratio and Ignition Retard	30	NOX < 365 tpy: \$2,497 NOX > 365 tpy: \$798		Capital and annual cost information was obtained from model engine data in the Alternative Control Techniques (ACT) Document -- NOx Emissions from Stationary Reciprocating Internal Combustion Engines (EPA 1993c). This control is the use of air/fuel and ignition retard to reduce NOx emissions. This control applies to natural gas-fired internal combustion engines with uncontrolled NOx emissions greater than 10 tons per year.	EPA 1993c, Pechan 2006
NonEGU Point	ICI Boilers - Gas	NBFIBG	Flue Gas Recirculation	40	25tpy < NOX < 50 tpy: \$23,290 50tpy < NOX < 100 tpy: \$12,423 NOX > 100 tpy: \$6,602		Capital and annual cost information was obtained from model engine data in the Alternative Control Techniques (ACT) Document -- NOx Emissions from Stationary Reciprocating Internal Combustion Engines (EPA 1993c). Gas from the boiler, economizer or air heater outlet is reintroduced to the furnace by fans and flues. Flue Gas Recirculation (FGR) is feasible as long as there is no minimum operational temperature/oxygen requirement for the boiler. Flue gas recirculation would lower the temperature range and oxygen levels in the boiler. Should there be a requirement for a minimum temperature or oxygen level (or both) from the boiler (for other processes at the facility) then FGR may not be feasible. Those requirements would need to be assessed on a source-by-source basis. In addition, FGR is generally implemented in conjunction with low NOx burners. FGR may also affect fan capacity, furnace pressure, burner pressure drop, and turndown stability. If these are critical parameters for processes associated with the boiler then FGR may be infeasible (MACTEC 2005b).	Bodnarik 2011, MACTEC 2005b, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010, EPA 2000e
NonEGU Point	ICI Boilers - Oil	NBFIBO	Flue Gas Recirculation	40	NOX > 25 tpy: \$13,000		Gas from the boiler, economizer or air heater outlet is reintroduced to the furnace by fans and flues. Flue Gas Recirculation (FGR) is feasible as long as there is no minimum operational temperature/oxygen requirement for the boiler. Flue gas recirculation would lower the temperature range and oxygen levels in the boiler. Should there be a requirement for a minimum temperature or oxygen level (or both) from the boiler (for other processes at the facility) then FGR may not be feasible. Those requirements would need to be assessed on a source-by-source basis. In addition, FGR is generally implemented in conjunction with low NOx burners. FGR may also affect fan capacity, furnace pressure, burner pressure drop, and turndown stability. If these are critical parameters for processes associated with the boiler then FGR may be infeasible (MACTEC 2005b).	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010
NonEGU Point	Glass Manufacturing - Flat	NCATCFGMFT	Catalytic Ceramic Filter	80	\$11,414		Marked as Emerging due to SRA review in Dec. 2016. (01/23/2017) Filter tubes have nanobits of proprietary catalyst are embedded throughout the filter walls. The system can achieve excellent NOx removal using liquid ammonia that is injected upstream of the filters, reacting with NOx at the catalyst to form nitrogen gas and water vapor. This control applies to general glass manufacturing operations.	ETS 2014
NonEGU Point	Gas Turbines - Natural Gas	NCATCGTNG	Catalytic Combustion	98	NOX < 365 tpy: \$1,330 DC < 26 MW: \$969 DC > 26 MW: \$535		This control is the use of catalytic combustion to reduce NOx emissions. Catalytic combustors reduce the amount of NOx created by oxidizing fuel at lower temperatures (and without a flame) than in conventional combustors. Catalytic combustion uses a catalytic bed to oxidize a lean air fuel mixture within a combustor instead of burning with a flame. The fuel and air mixture oxidizes at lower temperatures than in a conventional combustor, producing less NOx. Currently installed only on a few 1.4 MW combustion turbines, and commercially available for turbines rated up to 10 MW (CT-1).	BAAQMD 2010, DOE 1999, EPA 2018, RTI 2014
NonEGU Point	Glass Manufacturing - Container or Pressed	NCUPHGMCP	Cullet Preheat	5	\$6,812		This control is the use of cullet preheat technologies to reduce NOx emissions from container glass manufacturing operations.	EPA 1994c, DOE 2002, RTI 2014
NonEGU Point	Gas Turbines - Natural Gas	NDLNCGTNG	Dry Low NOx Combustion	84	NOX < 365 tpy: \$434 NOX > 365 tpy: \$188		This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control applies to large (83.3 MW to 161 MW) natural gas fired turbines with uncontrolled NOx emissions greater than 10 tons per year. LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).	Pechan 1998a, EPA 2002b, EPA 1993b, DOE 1999, RDC 2001, EPA 2018, RTI 2014
NonEGU Point	In-Process Fuel Use; Bituminous Coal; Gen	NDSRCBCGN	Selective Catalytic Reduction	90	\$4,377		This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control applies to operations with general (in process) bituminous coal use and uncontrolled NOx emissions greater than 10 tons per year. Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx. The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b). The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).	EPA 2007a

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NonEGU Point	In-Process; Bituminous Coal; Cement and Lime Kilns	NDSRCBCK	Selective Catalytic Reduction	90	\$3,064		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a, EPA 2017, EPA 2007b, Pechan 2006
NonEGU Point	Cement Manufacturing - Dry	NDSRCMDY	Selective Catalytic Reduction	90	\$6,703		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control applies to dry-process cement manufacturing and natural gas cement kilns with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a, EPA 2017, EPA 2007b, Pechan 2006
NonEGU Point	Cement Manufacturing - Wet	NDSRCMWT	Selective Catalytic Reduction	90	\$5,728		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control applies to large (>1 ton NOx per OSD) wet-process cement manufacturing with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2017, EPA 2007a, EPA 2007b, Pechan 2006

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NonEGU Point	Taconite Iron Ore Processing - Induration - Coal or Gas	NDSCRFFEP	Selective Catalytic Reduction	90	\$7,618		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a
NonEGU Point	Fluid Cat Cracking Units; Cracking Unit	NDSCRFFCCU	Selective Catalytic Reduction	90	\$8,269		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control is applicable to fluid catalytic cracking units with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a
NonEGU Point	In-Process; Process Gas; Coke Oven Gas	NDSCRFFGCO	Selective Catalytic Reduction	90	\$9,212		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. Applies to process gas fired ICI boilers with NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonEGU Point	Industrial Incinerators	NDSCRINDIN	Selective Catalytic Reduction	90	\$4,495		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control applies to industrial incinerators with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a
NonEGU Point	In-Process Fuel Use - Gas	NDSCRIPUG	Selective Catalytic Reduction	90	\$7,161		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control is applicable to operations with in-process natural gas usage and uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a
NonEGU Point	In-Process Fuel Use; Residual Oil; Gen	NDSCRUROGN	Selective Catalytic Reduction	90	\$6,446		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control is applicable to operations with in-process residual oil usage and uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a
NonEGU Point	Glass Manufacturing - General	NELBOGMGN	Electric Boost	30	\$9,673		<p>This control is the use of electric boost technologies to reduce NOx emissions from general glass manufacturing operations.</p>	DOE 2002

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NonEGU Point	Gas Turbines - Natural Gas	NEMXDGTNG	EMx and Dry Low NOx Combustion	99	NOx > 365 tpy: \$2,401		This control is the use of EMx in combination with dry low NOx combustion. EMx is a post-combustion catalytic oxidation and absorption technology that uses a two-stage catalyst/absorber system for the control of NOx as well as CO, VOC, and optionally SOx. A coated catalyst oxidizes NO to NO2, CO to CO2, and VOC to CO2 and water. The NO2 is then absorbed onto the catalyst surface where it is chemically converted to and stored as potassium nitrates and nitrites. A proprietary regeneration gas is periodically passed through the catalyst to desorb the NO2 from the catalyst and reduce it to elemental nitrogen (N2). EMx has been successfully demonstrated on several small combustion turbine projects up to 45 MW. The manufacturer has claimed that EMx can be effectively scaled up to larger turbines (CT-1).	BAAQMD 2010, DOE 1999, EmeraChem Power 2008, CH2MHill 2002a, CARB 2004, EPA 2018, RTI 2014
NonEGU Point	Gas Turbines - Natural Gas	NEMXGTNG	EMx	95	NOx > 365 tpy: \$2,401		Cost estimates for DLN combustion in 2008 dollars are not available. Thus, the total system cost in this analysis in 2008 dollars was developed from 1999 cost estimates for DLN combustion that were escalated to 2008 dollars and added to the available 2008 estimate for the EMx system. EMx is a post-combustion catalytic oxidation and absorption technology that uses a two-stage catalyst/absorber systems for the control of NOx, as well as CO and VOC. A coated catalyst oxidizes NO to NO2, CO to CO2, and VOC to CO2 and water. The NO2 is then absorbed onto the catalyst surface where it is chemically converted to and stored as potassium nitrates and nitrites. A proprietary regeneration gas is periodically passed through the catalyst to desorb the NO2 from the catalyst and reduce it to elemental nitrogen (N2). EMx has been successfully demonstrated on several small combustion turbine projects up to 45 MW. Capital and annual costs can be calculated using equations. Besides NOx, EMx also reduces fine particulate and VOC emissions. This control technology should only be used with natural gas-fired turbines since the catalyst/absorbers systems will not function optimally in the presence of less clean fuels (e.g., digester gas, process gas).	BAAQMD 2010, DOE 1999, EmeraChem Power 2008, CH2MHill 2002a, CARB 2004, EPA 2016, ERG 2017
NonEGU Point	Gas Turbines - Natural Gas	NEMXWGTNG	EMx and Water Injection	99	NOx > 365 tpy: \$3,467		This control is the use of EMx in combination with water injection.	BAAQMD 2010, EmeraChem Power 2008, EPA 2018, RTI 2014
NonEGU Point	Adipic Acid Manufacturing	NEXABADMF	Extended Absorption	86	\$156		Cost estimates for water injection in 2008 dollars are not available. Thus, the total system cost in this analysis in 2008 dollars was developed from 1999 cost estimates for water injection that were escalated to 2008 dollars and added to the available 2008 estimate for the EMx system. This control is the use of extended absorption technologies to reduce NOx emissions from adipic acid manufacturing operations. Extended absorption reduces NOx by increasing the efficiency of absorption by installing a single large tower, extending the height of existing absorption tower, or adding a second tower in series with an existing tower. As an add-on control, it is typically one of the latter two options as new plants are generally designed with a single large absorption tower as part of new plant design.	Pechan 1998a, EPA 1991
NonEGU Point	Nitric Acid Manufacturing	NEXABNAMF	Extended Absorption	95	\$832		This control is the use of extended absorption technologies to reduce NOx emissions from nitric acid manufacturing operations. Extended absorption reduces NOx by increasing the efficiency of absorption by installing a single large tower, extending the height of existing absorption tower, or adding a second tower in series with an existing tower. As an add-on control, it is typically one of the latter two options as new plants are generally designed with a single large absorption tower as part of new plant design.	Pechan 1998a, EPA 1991
NonEGU Point	IC Engines - Gas/ Diesel/ LPG	NIRICGD	Ignition Retard	25	NOx < 365 tpy: \$1,335 NOx > 365 tpy: \$850		This control is the use of ignition retard technologies to reduce NOx emissions. Capital and annual cost information was obtained from model engine data in the Alternative Control Techniques (ACT) Document -- NOx Emissions from Stationary Reciprocating Internal Combustion Engines (EPA 1993c).	EPA 1993c, Pechan 1998a
NonEGU Point	Internal Combustion Engines - Gas	NIRICGS	Ignition Retard	20	NOx < 365 tpy: \$1,769 NOx > 365 tpy: \$954		This control is the use of ignition retard technologies to reduce NOx emissions. This applies to small (<4,000 HP) natural gas-fired IC engines with uncontrolled NOx emissions greater than 10 tons per year. Capital and annual cost information was obtained from model engine data in the Alternative Control Techniques (ACT) Document -- NOx Emissions from Stationary Reciprocating Internal Combustion Engines (EPA 1993c).	EPA 1993c, Pechan 1998a
NonEGU Point	Internal Combustion Engines - Oil	NIRICOL	Ignition Retard	25	NOx < 365 tpy: \$1,335 NOx > 365 tpy: \$850		This control is the use of ignition retard technologies to reduce NOx emissions. This applies to small (<4,000 HP) oil IC engines with uncontrolled NOx emissions greater than 10 tons per year. Capital and annual cost information was obtained from model engine data in the Alternative Control Techniques (ACT) Document -- NOx Emissions from Stationary Reciprocating Internal Combustion Engines (EPA 1993c).	EPA 1993c, Pechan 1998a
NonEGU Point	Reciprocating IC Engines - Oil	NIRRICOIL	Ignition Retard	25	\$1,335		This control is the use of ignition retard technologies to reduce NOx emissions. This applies to small (<4,000 HP) oil IC engines with uncontrolled NOx emissions greater than 10 tons per year.	Pechan 2006
NonEGU Point	Lean Burn ICE - NG	NLCICE2SLBNG	Layered Combustion	97	NOx < 365 tpy: \$43,657 NOx > 365 tpy: \$1,723		Layered combustion - for Large Bore, 2 stroke, Lean Burn, Slow Speed (High Pressure Fuel Injection achieves 90% reduction; Turbocharging achieves 75% reduction; Precombustion chambers achieves 90% reduction; Cylinder Head Modifications). All retrofit combustion-related controls may not be available for all manufacturers and models of 2-stroke lean burn engines. Actual NOx emission rates would be engine design specific. Efficiency achieved may range from 60 to 90%, depending on the make/model of engine (approximate range of NOx emissions of 3.0 to 0.5 g/bhp-hr).	OTC 2012, RTI 2014
NonEGU Point	Lean Burn ICE - NG	NLCICE2SNG	Layered Combustion	97	\$5,695		Layered combustion - 2 stroke, Lean Burn, NG (Air Supply; Fuel Supply; Ignition; Electronic Controls; Engine Monitoring). Evaluation for 3 most representative made/models of 2 stroke LB compressor engines. All retrofit combustion-related controls may not be available for all manufacturers and models of 2-stroke lean burn engines. Actual NOx emission rates would be engine design specific. Efficiency achieved may range from 60 to 90%, depending on the make/model of engine (approximate range of NOx emissions of 3.0 to 0.5 g/bhp-hr).	OTC 2012, RTI 2014
NonEGU Point	Iron & Steel Mills - Reheating	NLEAISRH	Low Excess Air	13	\$2,289		The reduction in NOx emissions is achieved through the use of low excess air techniques, such that there is less available oxygen convert fuel nitrogen to NOx. This control applies to iron & steel reheating furnaces. Low excess air works by reducing levels of excess air to the combustor, usually by adjustments to air registers and/or fuel injection positions, or through control of overfire air dampers. The lower oxygen concentration in the burner zone reduces conversion of the fuel nitrogen to NOx. Also, under excess air conditions in the flame zone, a greater portion of fuel-bound nitrogen is converted to N2 therefore reducing the formation of fuel NOx (ERG 2000).	EPA 1993c, Pechan 1998a, ERG 2000, EPA 1994e
NonEGU Point	Lean Burn ICE - NG	NLEICENG	Low Emission Combustion	80	NOx < 365 tpy: \$1,384		Low Emission Combustion includes Precombustion chamber head and related equipment on a Lean Burn engine.	RTI 2014, SJVAPCD 2003, EPA 2018
NonEGU Point	Ammonia Prod; Feedstock Desulfurization	NLNBFAFDF	Low NOx Burner and Flue Gas Recirculation	60	NOx < 365 tpy: \$4,440 NOx > 365 tpy: \$1,023		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.	Pechan 1998a, EPA 1994d
<p>It is assumed that the superheated steam needed to regenerate the activated carbon bed used in the desulfurization process is the NOx source.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>								
NonEGU Point	In-Proc;Process Gas;Coke Oven/Blast Furn	NLNBFCOBF	Low NOx Burner and Flue Gas Recirculation	55	NOx < 365 tpy: \$5,532 NOx > 365 tpy: \$4,284		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.	Pechan 1998a, EPA 2002b
<p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>								

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NonEGU Point	Pri Cop Smel; Reverb Smelt Furn	NLNBFCRS	Low NOx Burner and Flue Gas Recirculation	60	\$1,301		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 2006
NonEGU Point	Fluid Cat Cracking Units; Cracking Unit	NLNBFFCCU	Low NOx Burner and Flue Gas Recirculation	55	NOX < 365 tpy: \$5,532 NOX > 365 tpy: \$4,284		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>The source of emissions for fluidized catalytic cracking come from process heaters and catalyst regenerators.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a, EPA 2002b
NonEGU Point	Fuel Fired Equip; Process Htrs; Pro Gas	NLNBFFPH	Low NOx Burner and Flue Gas Recirculation	55	NOX < 365 tpy: \$5,532 NOX > 365 tpy: \$4,284		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a
NonEGU Point	Ammonia - NG-Fired Reformers	NLNBFFRNG	Low NOx Burner and Flue Gas Recirculation	60	NOX < 365 tpy: \$4,440 NOX > 365 tpy: \$1,023		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to small (<1 ton NOx per OSD) ammonia production operations with natural gas-fired reformers and uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a, Pechan 2006
NonEGU Point	Ammonia - Oil-Fired Reformers	NLNBFFROL	Low NOx Burner and Flue Gas Recirculation	60	NOX < 365 tpy: \$1,942 NOX > 365 tpy: \$676		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 2006
NonEGU Point	ICI Boilers - Gas	NLNBIFBG	Low NOx Burner and Flue Gas Recirculation	61	25tpy < NOX < 50 tpy: \$25,768 50tpy < NOX < 100 tpy: \$13,798 NOX > 100 tpy: \$7,338		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Bodnarik 2011, MACTEC 2005b, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010, EPA 2000e
NonEGU Point	ICI Boilers - Oil	NLNBIFBO	Low NOx Burner and Flue Gas Recirculation	61	NOX > 25 tpy: \$14,054		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010
NonEGU Point	Iron & Steel Mills - Galvanizing	NLNBIFISV	Low NOx Burner and Flue Gas Recirculation	60	\$1,006		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to iron and steel galvanizing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994a, EPA 2002b

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NonEGU Point	Iron & Steel - In-Process Combustion - Process Gas - Coke Oven/ Blast Furnace	NLNBFSIPCG	Low NOx Burner and Flue Gas Recirculation	55	NOx < 365 tpy: \$5,532 NOx > 365 tpy: \$4,284		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to operations with in-process combustion (Process Gas - Coke Oven/ Blast Furnace) in the Iron & Steel industry with uncontrolled NOx emissions greater than 10 tons per year.	Pechan 1998a, EPA 2002b
NonEGU Point	Iron and Steel Production - Annealing or Soaking Pits	NLNBFSIPASP	Low NOx Burner and Flue Gas Recirculation	60	\$1,301		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to iron and steel annealing operations with uncontrolled NOx emissions greater than 10 tons per year. Soaking pits are a combustion source which can fire natural gas, oil or coal. Emissions of NOx are similar to boilers emissions. LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).	Pechan 1998a, EPA 2002b
NonEGU Point	Iron and Steel Production; Blast Heating or Reheating	NLNBFSIPBR	Low NOx Burner and Flue Gas Recirculation	77	\$659		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to reheating processes in iron production operations with blast heating stoves and uncontrolled NOx emissions greater than 10 tons per year. LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).	Pechan 1998a, EPA 1994e, EPA 2002b
NonEGU Point	Plastics Prod-Specific; (ABS) Resin	NLNBFSIPBR	Low NOx Burner and Flue Gas Recirculation	55	NOx < 365 tpy: \$5,532 NOx > 365 tpy: \$4,284		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to with acrylonitrile-butadiene-styrene plastic production uncontrolled NOx emissions greater than 10 tons per year. It is assumed that the NOx source is a process heater or boiler. LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).	Pechan 1998a, EPA 1994d
NonEGU Point	Sand/Gravel; Dryer	NLNBFSGDR	Low NOx Burner and Flue Gas Recirculation	55	NOx < 365 tpy: \$5,532 NOx > 365 tpy: \$4,284		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to small (<1 ton NOx per OSD) sand and gravel drying processes with uncontrolled NOx emissions greater than 10 tons per year. LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).	Pechan 1998a, EPA 1993a, Pechan 2006
NonEGU Point	Space Heaters - Distillate Oil	NLNBFSHDO	Low NOx Burner and Flue Gas Recirculation	60	NOx < 365 tpy: \$4,318 NOx > 365 tpy: \$1,318		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to small (<1 ton per OSD) residual oil-fired process heaters with uncontrolled NOx emissions greater than 10 tons per year. LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).	Pechan 1998a, EPA 1993a
NonEGU Point	Space Heaters - Natural Gas	NLNBFSHNG	Low NOx Burner and Flue Gas Recirculation	60	NOx < 365 tpy: \$4,440 NOx > 365 tpy: \$1,023		This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to small (<1 ton per OSD) LPG-fired process heaters with uncontrolled NOx emissions greater than 10 tons per year. LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).	Pechan 1998a, EPA 1994d

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NonEGU Point	Starch Mfg, Combined Operations	NLNBFSMCO	Low NOx Burner and Flue Gas Recirculation	55	NOX < 365 tpy: \$5,532 NOX > 365 tpy: \$4,284		<p>This control is the use of low NOx burner (LNB) technology and flue gas recirculation (FGR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to small (<1 ton per OSD) starch manufacturing with uncontrolled NOx emissions greater than 10 tons per year. The NOx source is generally a natural gas-fired dryer. Therefore, applicable control technologies are assumed to be LNB with FGR.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a
NonEGU Point	ICI Boilers - Oil	NLNBIBO	Low NOx Burner	47.5	NOX > 25 tpy: \$1,499		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>These technologies are prevalent in the electric power industry as well as in Industrial, Commercial and Institutional (ICI) boilers at present and increasingly used by ICIs, even at small sizes i.e., less than 10 MMBtu/hr (NESCAUM 2009).</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010
NonEGU Point	Iron & Steel - In-Process Combustion - Natural Gas or Coke Oven Process Gas	NLNBISPCG	Low NOx Burner	50	NOX < 365 tpy: \$3,815 NOX > 365 tpy: \$3,122		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. This control is applicable to operations with in-process combustion (Natural Gas or Coke Oven Process Gas) in the Iron & Steel industry with uncontrolled NOx emissions greater than 10 tons per year.</p>	Pechan 1998a, EPA 2002b
NonEGU Point	Iron & Steel Mills - Annealing	NLNBNISAN	Low NOx Burner and Selective Non-Catalytic Reduction	80	\$2,983		<p>This control is the use of low NOx burner (LNB) technology and selective non-catalytic reduction (SNCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O).</p> <p>This control is applicable to iron and steel annealing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water.</p> <p>Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx ; and ammonia slip.</p>	Pechan 1998a, EPA 1994e, EPA 2002b
EGU	Utility Boiler - Coal/Wall	NLNBOWBCW	Low NOx Burner and Over Fire Air	72	DC > 25 MW: \$698		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to wall fired (coal) utility boilers</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	EPA 2013, SRA 2016, EPA 2018
NonEGU Point	Sec Alum Prod; Smelting Furn/Reverb	NLNBASAF	Low NOx Burner	50	\$989		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to secondary aluminum production operations with smelting furnaces and uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994e

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NonEGU Point	Iron & Steel Mills - Annealing	NLNBSISAN	Low NOx Burner and Selective Catalytic Reduction	90	\$7,076		<p>This control is the use of low NOx burner (LNB) technology and selective catalytic reduction (SCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>This control is applicable to iron and steel annealing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b). Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 1994e, EPA 2002b
NonEGU Point	Asphaltic Conc; Rotary Dryer; Conv Plant	NLNBUACCP	Low NOx Burner	50	NOX < 365 tpy: \$3,815 NOX > 365 tpy: \$3,122		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a, Pechan 2006
NonEGU Point	Conv Coating of Prod; Acid Cleaning Bath	NLNBUCCAB	Low NOx Burner	50	NOX < 365 tpy: \$3,815 NOX > 365 tpy: \$3,122		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>The source of emissions for acid cleaning baths come from heating of the baths.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a
NonEGU Point	Coal Cleaning-Thrml Dryer; Fluidized Bed	NLNBUCCFB	Low NOx Burner	50	NOX < 365 tpy: \$1,338 NOX > 365 tpy: \$268		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>Thermal dryers are a direct-heat device.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994d, Pechan 2006
NonEGU Point	Ceramic Clay Mfg; Drying	NLNBUCCMD	Low NOx Burner	50	NOX < 365 tpy: \$3,815 NOX > 365 tpy: \$3,122		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994b, Pechan 2006

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NonEGU Point	Surf Coat Oper;Coating Oven Htr;Nat Gas	NLNBUCHNG	Low NOx Burner	50	NOX < 365 tpy: \$3,815 NOX > 365 tpy: \$3,122		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a, Pechan 2006
NonEGU Point	Cement Manufacturing - Wet or Dry	NLNBUCMWD	Low NOx Burner	27	\$653		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to wet-process cement manufacturing operations with indirect-fired kilns (SCC 30500706) with uncontrolled NOx emissions greater than 10 tons per year. This control applies to dry-process cement manufacturing operations with indirect-fired kilns with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	EPA 1994b, ECR 2000
NonEGU Point	Fuel Fired Equip; Furnaces; Natural Gas	NLNBUFFNG	Low NOx Burner	50	\$989		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to natural gas fired equipment with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994e, EPA 2002b
NonEGU Point	Fbrglass Mfg; Txtile-Type Fbr; Recup Furn	NLNBUFMTF	Low NOx Burner	40	\$2,931		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to textile-type fiberglass manufacturing operations with recuperative furnaces and uncontrolled NOx emissions greater than 10 tons per year. Recuperative furnaces may be gas- or oil-fired.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994c
NonEGU Point	Ammonia - NG-Fired Reformers	NLNBUFRNG	Low NOx Burner	50	NOX < 365 tpy: \$1,422 NOX > 365 tpy: \$937		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 2002b, EPA 1994d, INCOG 2008, Pechan 2006
NonEGU Point	Ammonia - Oil-Fired Reformers	NLNBUFROL	Low NOx Burner	50	NOX < 365 tpy: \$694 NOX > 365 tpy: \$746		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 2006
NonEGU Point	Glass Manufacturing - Container	NLNBUGMCN	Low NOx Burner	40	\$1,436		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to container glass manufacturing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994c, EC 2013, EPA 2018, RTI 2014

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NonEGU Point	Glass Manufacturing - Flat	NLNBUGMFT	Low NOx Burner	40	\$573		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to flat glass manufacturing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994c, EC 2013, EPA 2018, RTI 2014
NonEGU Point	Glass Manufacturing - Pressed	NLNBUGMPD	Low NOx Burner	40	\$2,601		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to pressed glass manufacturing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994c
NonEGU Point	Gas Turbines - Natural Gas	NLNBUGTNG	Low NOx Burner	84	NOX < 365 tpy: \$850 NOX > 365 tpy: \$173		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to large (83.3 MW to 161 MW) natural gas fired turbines with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 2002b, EPA 1993b, EPA 2018, RTI 2014
NonEGU Point	ICI Boilers - Coal/Wall	NLNBUICBW	Low NOx Burner	47.5	25tpy < NOX < 100 tpy: \$8,057 100tpy < NOX < 250 tpy: \$2,694 NOX > 250 tpy: \$909		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>These technologies are prevalent in the electric power industry as well as in Industrial, Commercial and Institutional (ICI) boilers at present and increasingly used by ICIs, even at small sizes i.e., less than 10 MMBtu/hr (NESCAUM 2009).</p>	Bodnarik 2011, MACTEC 2005b, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010, EPA 2000e
NonEGU Point	ICI Boilers - Gas	NLNBUIBG	Ultra Low NOx Burner	75	25tpy < NOX < 50 tpy: \$8,605 50tpy < NOX < 100 tpy: \$4,603 NOX > 100 tpy: \$2,451		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>These technologies are prevalent in the electric power industry as well as in Industrial, Commercial and Institutional (ICI) boilers at present and increasingly used by ICIs, even at small sizes i.e., less than 10 MMBtu/hr (NESCAUM 2009).</p>	Staudt 2011, Bodnarik 2011, MACTEC 2005b, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010, EPA 2000e
NonEGU Point	Iron & Steel Mills - Annealing	NLNBUISAN	Low NOx Burner	50	\$989		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to iron and steel annealing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994e, EPA 2002b
NonEGU Point	Iron & Steel Mills - Galvanizing	NLNBUISGV	Low NOx Burner	50	\$850		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to iron and steel galvanizing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994e, EPA 2002b

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NonEGU Point	Iron & Steel Mills - Reheating	NLNBUISRH	Low NOx Burner	66	\$520		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to iron and steel reheating operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994e, EPA 2002b
NonEGU Point	Lime Kilns	NLNBULMKN	Low NOx Burner	30	\$971		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to lime kilns with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 2002b, EPA 1994b, Pechan 2006
NonEGU Point	In-Process Fuel Use; Natural Gas; Gen	NLNBUNGGN	Low NOx Burner	50	NOX < 365 tpy: \$3,815 NOX > 365 tpy: \$3,122		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to operations with in-process natural gas usage and uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a, EPA 2002b
NonEGU Point	In-Process; Process Gas; Coke Oven Gas	NLNBUPGCO	Low NOx Burner	50	NOX < 365 tpy: \$4,370 NOX > 365 tpy: \$3,122		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to operations with in-process coke oven gas usage and uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 2002b
NonEGU Point	In-Process Fuel Use; Residual Oil; Gen	NLNBURROGN	Low NOx Burner	37	NOX < 365 tpy: \$4,370 NOX > 365 tpy: \$1,231		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to operations with in-process residual oil usage and uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1993a, EPA 2002b
NonEGU Point	Steel Foundries; Heat Treating Furn	NLNBUSFHT	Low NOx Burner	50	\$989		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to heat treating operations at steel foundries with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994e, EPA 2002b
NonEGU Point	Space Heaters - Distillate Oil	NLNBUSHDO	Low NOx Burner	50	NOX < 365 tpy: \$2,046 NOX > 365 tpy: \$3,590		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to distillate oil-fired space heaters with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994d

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NonEGU Point	Space Heaters - Natural Gas	NLNBUSHNG	Low NOx Burner	50	NOX < 365 tpy: \$1,422 NOX > 365 tpy: \$1,127		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control is applicable to natural gas-fired space heaters with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	Pechan 1998a, EPA 1994d
EGU	Utility Boiler - Coal/Wall	NLNBUBCW	Low NOx Burner	57	DC > 25 MW: \$646		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to wall fired (coal) utility boilers</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	EPA 2013, SRA 2016, EPA 2018
EGU	Utility Boiler - Coal/Tangential	NLNC1UBCT	Low NOx Coal-and-Air Nozzles with cross-Coupled Overfire Air	42	DC > 25 MW: \$440		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to wall fired (coal) utility boilers</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	EPA 2013, SRA 2016, EPA 2018
EGU	Utility Boiler - Coal/Tangential	NLNC2UBCT	Low NOx Coal-and-Air Nozzles with separated Overfire Air	47	DC > 25 MW: \$549		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to wall fired (coal) utility boilers</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	EPA 2013, SRA 2016, EPA 2018
EGU	Utility Boiler - Coal/Tangential	NLNC3UBCT	Low NOx Coal-and-Air Nozzles with Cross-Coupled and Separated Overfire Air	62	DC > 25 MW: \$490		<p>This control is the use of low NOx burner (LNB) technology to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another.</p> <p>This control applies to wall fired (coal) utility boilers</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNBs create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNBs create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p>	EPA 2013, SRA 2016, EPA 2018

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NonEGU Point	ICI Boilers - Coal/Wall	NLNSCRBCW	Ultra Low NOx Burner and Selective Catalytic Reduction	91	25tpy < NOX < 100 tpy: \$17,697 100tpy < NOX < 250 tpy: \$6,312 NOX > 250 tpy: \$2,343		<p>This control is the use of low NOx burner (LNB) technology and selective catalytic reduction (SCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Bodnarik 2011, MACTEC 2005b, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010, EPA 2000e
NonEGU Point	ICI Boilers - Gas	NLNSCRIBG	Ultra Low NOx Burner and Selective Catalytic Reduction	91	25tpy < NOX < 50 tpy: \$31,198 50tpy < NOX < 100 tpy: \$17,166 NOX > 100 tpy: \$9,300		<p>This control is the use of low NOx burner (LNB) technology and selective catalytic reduction (SCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Bodnarik 2011, MACTEC 2005b, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010, EPA 2000e

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NonEGU Point	ICI Boilers - Oil	NLNSCRIBO	Ultra Low NOx Burner and Selective Catalytic Reduction	91	NOX > 25 tpy: \$4,076		<p>This control is the use of low NOx burner (LNB) technology and selective catalytic reduction (SCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010
NonEGU Point	ICI Boilers - Coal/Wall	NLNSCRIBCW	Ultra Low NOx Burner and Selective Non-Catalytic Reduction	69.5	25tpy < NOX < 100 tpy: \$12,875 100tpy < NOX < 250 tpy: \$4,877 NOX > 250 tpy: \$2,143		<p>This control is the use of low NOx burner (LNB) technology and selective non-catalytic reduction (SNCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O).</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water.</p> <p>Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx ; and ammonia slip.</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010

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NonEGU Point	ICI Boilers - Gas	NLNSNCRIBG	Low NOx Burner and Selective Non-Catalytic Reduction	69.5	25tpy < NOX < 50 tpy: \$21,826 50tpy < NOX < 100 tpy: \$12,047 NOX > 100 tpy: \$6,740		<p>This control is the use of low NOx burner (LNB) technology and selective non-catalytic reduction (SNCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O).</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water.</p> <p>Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx ; and ammonia slip.</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010
NonEGU Point	ICI Boilers - Oil	NLNSNCRIBO	Low NOx Burner and Selective Non-Catalytic Reduction	69.5	NOX > 25 tpy: \$3,361		<p>This control is the use of low NOx burner (LNB) technology and selective non-catalytic reduction (SNCR) to reduce NOx emissions. LNBs reduce the amount of NOx created from reaction between fuel nitrogen and oxygen by lowering the temperature of one combustion zone and reducing the amount of oxygen available in another. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O).</p> <p>LNBs are designed to "stage" combustion so that two combustion zones are created, one fuel-rich combustion and one at a lower temperature. Staging techniques are usually used by LNB to supply excess air to cool the combustion process or to reduce available oxygen in the flame zone. Staged-air LNB's create a fuel-rich reducing primary combustion zone and a fuel-lean secondary combustion zone. Staged-fuel LNB's create a lean combustion zone that is relatively cool due to the presence of excess air, which acts as a heat sink to lower combustion temperatures (EPA 2002b).</p> <p>SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water.</p> <p>Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx ; and ammonia slip.</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2010
NonEGU Point	Cement Manufacturing - Wet or Dry	NMKFRCMWD	Mid-Kiln Firing	41	\$82		<p>This control is the use of mid-kiln firing to reduce NOx emissions. This control applies to wet-process or dry-process cement manufacturing with uncontrolled NOx emissions greater than 10 tons per year.</p>	ECR 2000
NonEGU Point	External Combustion Boilers, Elec Gen, Nat Gas	NNGRECBNG	Natural Gas Reburn	50	\$2,821		<p>Natural gas reburning (NGR) involves add-on controls to reduce NOx emissions. NGR is a combustion control technology in which part of the main fuel heat input is diverted to locations above the main burners, called the reburn zone. As flue gas passes through the reburn zone, a portion of the NOx formed in the main combustion zone is reduced by hydrocarbon radicals and converted to molecular nitrogen (N2).</p> <p>This control applies to non-tangentially fired Natural Gas external combustion boilers with capacity of at least 100 Million BTU/hr.</p> <p>In a reburn boiler, fuel is injected into the upper furnace region to convert the NOx formed in the primary combustion zone to molecular N2 and H2O. In general, the overall process occurs within three zones of the boiler; the combustion zone, the gas reburning zone, and the burnout zone (ERG 2000). In the combustion zone the amount of fuel is reduced and the burners may be operated at the lowest excess air level. In the gas reburning zone the fuel not used in the combustion zone is injected to create a fuel-rich region where radicals can react with NOx to form molecular Nitrogen. In the burnout zone a separate overfire air system redirects air from the primary combustion zone to ensure complete combustion of unreacted fuel leaving the reburning zone. Operational parameters that affect the performance of reburn include reburn zone stoichiometry, residence time in the reburn zone, reburn fuel carrier gas and temperature and O2 levels in the burnout zone (ERG 2000).</p>	EPA 2007b
NonEGU Point	Industrial NG ICE, SCCs with technology not specified	NNSCRAFRINGNS	Non-Selective Catalytic Reduction or Adjust Air Fuel Ratio and Ignition Retard	39	NOX < 365 tpy: \$2,219 NOX > 365 tpy: \$772		<p>This control measure is for natural gas fired internal combustion engines where the firing technology is not specified as to Rich Burn or Lean Burn. Existing control measures are applied based on the estimated percentage of lean-burn engines (85%) and rich-burn engines (15%). Adjust Air to Fuel Ratio and Ignition Retard (NAFRICGS) is used for lean-burn engines and NSCR (NNSCRING14) is used for rich-burn engines.</p>	Pechan 2006, EPA 2007b, INGAA 2014, CSRA 2016
NonEGU Point	Industrial NG ICE, 4cycle (rich)	NNSCRING14	Non-Selective Catalytic Reduction	90	\$610		<p>NSCR is achieved by placing a catalyst in the exhaust stream of the engine. The exhaust passes over the catalyst, usually a noble metal (platinum, rhodium or palladium) which reduces the reactants to N2, CO2 and H2O (NJDEP 2003). Typical exhaust temperatures for effective removal of NOx are 800-1200 degrees Fahrenheit. An oxidation catalyst using additional air can be installed downstream of the NSCR catalyst for additional CO and VOC control. This includes 4-cycle naturally aspirated engines and some 4-cycle turbocharged engines. Engines operating with NSCR require air/fuel control to maintain high reduction effectiveness.</p>	EPA 2007b, NJDEP 2003
NonEGU Point	Industrial NG ICE, SCCs with technology not specified	NNSCRLCNGNS	Non-Selective Catalytic Reduction or Layered Combustion	95.95	\$4,924		<p>This control measure is for natural gas fired internal combustion engines where the firing technology is not specified as to Rich Burn or Lean Burn. Existing control measures are applied based on the estimated percentage of lean-burn engines (85%) and rich-burn engines (15%). Layered combustion (NLICICE2SNG) is used for lean-burn engines and NSCR (NNSCRING14) is used for rich-burn engines.</p>	EPA 2007b, OTC 2012, INGAA 2014, CSRA 2016

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NonEGU Point	Industrial NG ICE, SCCs with technology not specified	NNSCRLECNNGNS	Non-Selective Catalytic Reduction or Low Emission Combustion	87.45	\$667		This control measure is for natural gas fired internal combustion engines where the firing technology is not specified as to Rich Burn or Lean Burn. Existing control measures are applied based on the estimated percentage of lean-burn engines (85%) and rich-burn engines (15%). Low emission combustion (NLEICCEGAS) is used for lean-burn engines and NSCR (NNSCRING14) is used for rich-burn engines.	EPA 2007b, CARB 2001, INCAA 2014, CSRA 2016
NonEGU Point	Nitric Acid Manufacturing	NNSCRNAMF	Non-Selective Catalytic Reduction	98	\$954		NSCR is achieved by placing a catalyst in the exhaust stream of the engine. The exhaust passes over the catalyst, usually a noble metal (platinum, rhodium or palladium) which reduces the reactants to N2, CO2 and H2O (NJDEP 2003). Typical exhaust temperatures for effective removal of NOx are 800-1200 degrees Fahrenheit. An oxidation catalyst using additional air can be installed downstream of the NSCR catalyst for additional CO and VOC control. This includes 4-cycle naturally aspirated engines and some 4-cycle turbocharged engines. Engines operating with NSCR require air/fuel control to maintain high reduction effectiveness.	Pechan 2006, NJDEP 2003
NonEGU Point	Glass Manufacturing - General	NOEASGMGN	Oxygen Enriched Air Staging	65	\$797		Developed by the Gas Technology Institute (GTI), Oxygen-Enriched Air Staging (OEAS) is a retrofit that provides NOx reduction on all endport and sideport airfired regenerative glass melters. OEAS involves reducing the amount of primary combustion air entering through the firing port. The lower air to fuel ratio decreases NOx formation in the flame, but incomplete combustion generates carbon monoxide and leaves some hydrocarbons unburned. Air or oxygenenriched air is injected into the furnace near the exhaust port to complete combustion in a second stage within the furnace in order to assure complete combustion and heat release. The second stage completes combustion without increasing NOx production. The process is the most economical control technology for NOx emissions because fuel consumption is not increased. The technology also has no effect upon glass quality or furnace superstructure, and can even increase furnace productivity.	DOE 2002, EPA 2010, EPA 2012
NonEGU Point	Petroleum Refinery Gas-Fired Process Heaters	NPRGPHEO2C	Excess O3 Control	37	NOX > 25 tpy: \$70		Petroleum Refinery Gas-Fired Process Heaters; Excess O2 Control	MACTEC 2005x, CSRA 2017, EPA 2015, EPA 2018
NonEGU Point	Petroleum Refinery Gas-Fired Process Heaters	NPRGPHSC95	SCR-95%	84	NOX > 25 tpy: \$12,352		Petroleum Refinery Gas-Fired Process Heaters; SCR-95%	MACTEC 2005x, CSRA 2017, EPA 2015, EPA 2018
NonEGU Point	Petroleum Refinery Gas-Fired Process Heaters	NPRGPHSCR	Selective Catalytic Reduction	71	NOX > 25 tpy: \$10,798		Petroleum Refinery Gas-Fired Process Heaters; Selective Catalytic Reduction	MACTEC 2005x, CSRA 2017, EPA 2015, EPA 2018
NonEGU Point	Petroleum Refinery Gas-Fired Process Heaters	NPRGPHULNB	Ultra-Low NOx Burner	53	NOX > 25 tpy: \$1,803		Petroleum Refinery Gas-Fired Process Heaters; Ultra Low NOX Burners	MACTEC 2005x, CSRA 2017, EPA 2015, EPA 2018
NonPoint	Industrial Coal Combustion	NR25COL96	RACT to 25 tpy (Low NOx Burner)	21	NOX > 25 tpy: \$2,341		The RACT control technology used is the addition of a low NOx burner to reduce NOx emissions. This standard applies to sources with boilers fueled by coal that emit over 25 tpy NOx.	Pechan 2006, Pechan 1998x, Pechan 1996
NonPoint	Industrial NG Combustion	NR25NGC96	RACT to 25 tpy (Low NOx Burner)	31	NOX > 25 tpy: \$1,335		The RACT control technology used is the addition of a low NOx burner to reduce NOx emissions. This standard applies to sources with boilers fueled by natural gas that emit over 25 tpy NOx.	Pechan 2006, Pechan 1998x, Pechan 1996
NonPoint	Industrial Oil Combustion	NR25OIL96	RACT to 25 tpy (Low NOx Burner)	36	NOX > 25 tpy: \$2,046		The RACT control technology used is the addition of a low NOx burner to reduce NOx emissions. This standard applies to sources with boilers fueled by oil that emit over 25 tpy NOx.	Pechan 2006, Pechan 1998x, Pechan 1996
NonPoint	Industrial Coal Combustion	NR50COL96	RACT to 50 tpy (Low NOx Burner)	21	NOX > 50 tpy: \$2,341		The RACT control technology used is the addition of a low NOx burner to reduce NOx emissions. This standard applies to sources with boilers fueled by coal that emit over 50 tpy NOx.	Pechan 2006, Pechan 1998x, Pechan 1996
NonPoint	Industrial NG Combustion	NR50NGC96	RACT to 50 tpy (Low NOx Burner)	31	NOX > 50 tpy: \$1,335		The RACT control technology used is the addition of a low NOx burner to reduce NOx emissions. This standard applies to sources with boilers fueled by natural gas that emit over 50 tpy NOx.	Pechan 2006, Pechan 1998x, Pechan 1996
NonPoint	Industrial Oil Combustion	NR50OIL96	RACT to 50 tpy (Low NOx Burner)	36	NOX > 50 tpy: \$2,046		The RACT control technology used is the addition of a low NOx burner to reduce NOx emissions. This standard applies to sources with boilers fueled by oil that emit over 50 tpy NOx.	Pechan 2006, Pechan 1998x, Pechan 1996
EGU	Utility Boiler - Coal/Tangential	NSCR_UBCTx	Selective Catalytic Reduction	90	25 MW < DC < 99 MW: \$2,674 100 MW < DC < 299 MW: \$2,269 300 MW < DC < 499 MW: \$2,146 500 MW < DC < 699 MW: \$2,083 DC > 700 MW: \$2,019		This control is the use of selective catalytic reduction add-on controls to tangentially coal-fired utility boilers for the reduction of NOx emissions. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) with a nitrogen based reducing reagent, such as ammonia or urea, to reduce the NOx into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.	EPA 1998c, EPA 2001, EPA 2004, MassDEP 2002, EPA 2017, EPA 2013, SRA 2016, EPA 2018
<p>Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx. Selective Catalytic Reduction (SCR) systems are among the post-combustion NOx control systems that can be effective in controlling mercury. This is based on recent pilot-scale tests that indicate that SNCR and SCR systems may enhance Hg capture under some conditions by oxidizing Hg0 (MassDEP 2002). Researches are investigating the possibility of Hg0 to Hg2+ conversion in SCR systems as a possible result of ammonia on fly ash mercury reactions. In the SCR process, a catalyst (such as vanadium, titanium, platinum, or zeolite) is used in a bed reactor, and the NOx reduction occurs at the surface of the catalyst bed with the help of a reducing agent (diluted ammonia or urea, which generates ammonia in the process). The ammonia mixture is injected into the flue gas upstream of the metal catalyst bed reactor, which is located upstream of a PM or SO2 control device (usually between the economizer outlet and air heater inlet, where temperatures range from 230 to 400oC). Recent pilot-scale tests indicate that SCR systems can enhance Hg capture under some conditions by oxidizing Hg0. On the plant-size scale, only one set of tests have been performed to measure the effectiveness of SCR systems. Application of SCR system, combined with spray dryer absorber was tested at a plant which was firing bituminous coal. The test results indicated greater than 95 percent mercury removal for the combined co-control systems (MassDEP 2002).</p>								

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EGU	Utility Boiler - Oil-Gas/Tangential	NSCR_UBOT	Selective Catalytic Reduction	80	DC > 25 MW: \$1,621		<p>This control is the selective catalytic reduction of NOx through add-on controls to tangentially fired (oil/gas) utility boilers. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) with a nitrogen based reducing reagent, such as ammonia or urea, to reduce the NOx into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>This control applies to tangentially natural-gas fired electricity generation sources with nameplate capacity greater than 100 MW.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2010c, EPA 1998c, EPA 2017, EPA 2013, EPA 2018
EGU	Utility Boiler - Oil-Gas/Wall	NSCR_UBOW	Selective Catalytic Reduction	80	DC > 25 MW: \$1,621		<p>This control is the selective catalytic reduction of NOx through add-on controls to wall fired (oil/gas) utility boilers. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) with a nitrogen based reducing reagent, such as ammonia or urea, to reduce the NOx into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to large (>100 million Btu/hr) natural-gas fired electricity generation sources with nameplate capacity greater than 100 MW, excluding tangentially fired sources.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2010c, EPA 1998c, EPA 2017, EPA 2013, EPA 2018

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NonEGU Point	Cement Manufacturing - Dry2	NSCRCMDY	Selective Catalytic Reduction	85	\$5,844		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control applies to dry-process cement manufacturing and Natural Gas Cement Kilns with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 2006, EPA 2017
NonEGU Point	Gas Turbines - Natural Gas	NSCRDGTNG	SCR + DLN Combustion	94.6	DC > 26 MW: \$564 DC < 26 MW: \$2,603 DC < 26 MW: \$1,431		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>This control applies to natural gas fired turbines with NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 2002b, EPA 1993b, EPA 2010c, DOE 1999, EmeraChem Power 2008, CH2MHill 2002a, RDC 2001, EPA 2008d, EPA 2018, RTI 2014
NonEGU Point	Ammonia - NG-Fired Reformers	NSCRFRNG	Selective Catalytic Reduction	90	\$3,421		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to natural-gas fired reformers involved in the production of ammonia with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 2007a, Pechan 1998a, EPA 2002b

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NonEGU Point	Ammonia - Oil-Fired Reformers	NSCRFROL	Selective Catalytic Reduction	80	NOx < 365 tpy: \$2,567 NOx > 365 tpy: \$1,405		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to oil fired reformers involved in the production of ammonia with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 2006
NonEGU Point	Glass Manufacturing - Container	NSCRGMCN	Selective Catalytic Reduction	75	\$2,135		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to glass-container manufacturing processes with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 1994c, EC 2013, EPA 2018, RTI 2014

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NonEGU Point	Glass Manufacturing - Flat	NSCRGMFT	Selective Catalytic Reduction	75	\$1,055		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to large(>1 ton NOx per OSD) flat-glass manufacturing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 1994c, EC 2013, EPA 2018, RTI 2014
NonEGU Point	Glass Manufacturing - Pressed	NSCRGMPD	Selective Catalytic Reduction	75	\$4,388		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to pressed-glass manufacturing operations with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 1994c
NonEGU Point	ICI Boilers - Coal	NSCRICBC	Selective Catalytic Reduction	90	\$8,194		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001). A SCR will impose an energy impact on the host boiler. The losses attributable to this technology include: compressor, reactor pressure loss, and steam i.e., sootblowing (NESCAUM 2009).</p>	EPA 2017, Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2019

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NonEGU Point	ICI Boilers - Gas	NSCRICBG	Selective Catalytic Reduction	90	\$11,441		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001). A SCR will impose an energy impact on the host boiler. The losses attributable to this technology include: compressor, reactor pressure loss, and steam i.e., sootblowing (NESCAUM 2009).</p>	EPA 2017, Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2019
NonEGU Point	ICI Boilers - Oil	NSCRICBO	Selective Catalytic Reduction	90	\$8,914		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001). A SCR will impose an energy impact on the host boiler. The losses attributable to this technology include: compressor, reactor pressure loss, and steam i.e., sootblowing (NESCAUM 2009).</p>	EPA 2017, Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2018, ERG 2019
NonEGU Point	Lean Burn ICE - NG	NSCRICE4SNG	Selective Catalytic Reduction	90	\$4,013		<p>SCR can be used on Lean Burn, NG engines. Assumed SCR can meet NOx emissions of 0.89 g/bh-hr. This is a Known technology, however there is indication that applicability is engine/unit specific.</p>	OTC 2012, SJVAPCD 2003, CARB 2001, EPA 2018, RTI 2014
NonEGU Point	ICE - Diesel	NSCRICEDS	Selective Catalytic Reduction	90	NOX < 365 tpy: \$11,747		<p>SCR can be used on Diesel engines.</p>	EPA 2010a, RTI 2014
NonEGU Point	Internal Combustion Engines - Oil	NSCRICOL	Selective Catalytic Reduction	80	NOX < 365 tpy: \$4,058 NOX > 365 tpy: \$1,595		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to oil-fired internal combustion engines with NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	EPA 1993c, Pechan 1998a

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NonEGU Point	Iron & Steel Mills - Annealing2	NSCRISAN	Selective Catalytic Reduction	90	\$7,618		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to iron and steel annealing operations with NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 1993a, EPA 2002b, EPA 2007a, EPA 2007g, EPA 2001
NonEGU Point	Iron & Steel - In-Process Combustion - Bituminous Coal	NSCRISIPCC	Selective Catalytic Reduction	90	\$4,377		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control is applicable to operations with in-process combustion (Bituminous Coal) in the Iron & Steel industry with uncontrolled NOx emissions greater than 10 tons per year.</p>	EPA 2007a, EPA 2010b
NonEGU Point	Iron & Steel - In-Process Combustion - Natural Gas and Process Gas - Coke Oven Gas	NSCRISIPCG	Selective Catalytic Reduction	90	\$7,161		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control is applicable to operations with in-process combustion (Natural Gas and Process Gas - Coke Oven Gas) in the Iron & Steel industry.</p>	EPA 2007a, EPA 2010b
NonEGU Point	Iron & Steel - In-Process Combustion - Residual Oil	NSCRISIPCO	Selective Catalytic Reduction	90	\$6,446		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. This control is applicable to operations with in-process combustion (Residual Oil) in the Iron & Steel industry with uncontrolled NOx emissions greater than 10 tons per year.</p>	EPA 2007a, EPA 2010b
NonEGU Point	Nitric Acid Manufacturing2	NSCRNAMF	Selective Catalytic Reduction	90	\$1,174		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to nitric acid manufacturing operations with NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 1991, EPA 2002b, EPA 2007a, EPA 2007g, EPA 2001

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NonEGU Point	Gas Turbines - Natural Gas	NSCRSGTNG	Selective Catalytic Reduction and Steam Injection	95	DC > 26 MW: \$824 DC < 26 MW: \$3,716 DC < 26 MW: \$1,995		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures. Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p> <p>This control applies to natural gas fired turbines with NOx emissions greater than 10 tons per year.</p>	<p>Pechan 1998a, EPA 2002b, EPA 1993b, EPA 2010c, DOE 1999, EmeraChem Power 2008, EPA 2018, RTI 2014</p>
NonEGU Point	Space Heaters - Distillate Oil	NSCRSHDO	Selective Catalytic Reduction	80	NOX < 365 tpy: \$4,821 NOX > 365 tpy: \$2,619		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to distillate oil-fired space heaters with NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	<p>Pechan 1998a, EPA 1994d, EPA 2001</p>
NonEGU Point	Space Heaters - Natural Gas	NSCRSHNG	Selective Catalytic Reduction	80	NOX < 365 tpy: \$4,960 NOX > 365 tpy: \$2,098		<p>This control is the selective catalytic reduction of NOx through add-on controls. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>Applies to natural gas fired space heaters with NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	<p>Pechan 1998a, EPA 1994d, EPA 2001</p>

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NonEGU Point	Gas Turbines - Natural Gas	NSCRWG1NG	Selective Catalytic Reduction and Water Injection	94.1	DC > 26 MW: \$1,547 DC < 26 MW: \$4,034 DC < 26 MW: \$1,981		<p>This control is the selective catalytic reduction of NOx through add-on controls in combination with water injection. SCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). The SCR utilizes a catalyst to increase the NOx removal efficiency, which allows the process to occur at lower temperatures.</p> <p>This control applies to natural gas-fired gas turbines with uncontrolled NOx emissions greater than 10 tons per year.</p> <p>Selective Catalytic Reduction (SCR) has been widely applied to stationary source, fossil fuel-fired, combustion units for emission control since the early 1970s. SCR is typically implemented on units requiring a higher level of NOx control than achievable by SNCR or other combustion controls (EPA 2002b). Like SNCR, SCR is based on the chemical reduction of the NOx molecule. The primary difference between SNCR and SCR is that SCR uses a metal-based catalyst to increase the rate of reaction (EPA 2002b). A nitrogen based reducing reagent, such as ammonia or urea, is injected into the flue gas. The reagent reacts selectively with the flue gas NOx within a specific temperature range and in the presence of the catalyst and oxygen to reduce the NOx.</p> <p>The use of a catalyst results in two advantages of the SCR process over SNCR, the higher NOx reduction efficiency and the lower and broader temperature ranges. However, the decrease in reaction temperature and increase in efficiency is accompanied by a significant increase in capital and operating costs (EPA 2002b). The cost increase is due to the large amount of catalyst required. The SCR system can utilize either aqueous or anhydrous ammonia as the reagent. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Today, catalyst formulations include single component, multi-component, or active phase with a support structure. Most catalyst formulations contain additional compounds or supports, providing thermal and structural stability or to increase surface area (EPA 2002b).</p> <p>The rate of reaction determines the amount of NOx removed from the flue gas. The important design and operational factors that affect the rate of reduction include: reaction temperature range; residence time available in the optimum temperature range; degree of mixing between the injected reagent and the combustion gases; uncontrolled NOx concentration level; molar ratio of injected reagent to uncontrolled NOx; ammonia slip; catalyst activity; catalyst selectivity; pressure drop across the catalyst; catalyst pitch; catalyst deactivation; and catalyst management (EPA 2001).</p>	Pechan 1998a, EPA 2002b, EPA 1993b, EPA 2010c, DOE 1999, EmeraChem Power 2008, EPA 2008d, EPA 2018, RTI 2014
NonEGU Point	Cement Manufacturing - Dry	NSNCRMDY	Selective Non-Catalytic Reduction - Ammonia	50	\$1,474		<p>This control is the reduction of NOx emission through ammonia based selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>This control applies to dry-process cement manufacturing operations with uncontrolled NOx emissions greater than 10 tons per year.</p>	EPA 2017, Pechan 2006
NonEGU Point	In-Process; Bituminous Coal; Cement Kiln	NSNCRBCK	Selective Non-Catalytic Reduction	50	\$1,335		<p>This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>This control applies to bituminous coal-fired cement kilns with uncontrolled NOx emissions greater than 10 tons per year.</p>	Pechan 2006
NonEGU Point	In-Process Fuel Use; Bituminous Coal; Gen	NSNCRBCGN	Selective Non-Catalytic Reduction	40	NOX < 365 tpy: \$2,185 NOX > 365 tpy: \$1,630		<p>This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>This control applies to operations with general (in process) bituminous coal use and uncontrolled NOx emissions greater than 10 tons per year.</p>	Pechan 1998a, EPA 1994d, EPA 2002b

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NonEGU Point	In-Process; Bituminous Coal; Lime Kiln	NSNCRBCLK	Selective Non-Catalytic Reduction	50	\$1,335		This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 1998a, EPA 2002b, EPA 1994b, Pechan 2006
NonEGU Point	Comm./Inst. Incinerators	NSNCRCIIN	Selective Non-Catalytic Reduction	45	\$1,960		This control applies to bituminous coal-fired lime kilns with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 1998a, EPA 2002b, Radian 1994
NonEGU Point	Cement Manufacturing - Dry	NSNCRCMDY	Selective Non-Catalytic Reduction	50	\$1,335		This control applies to commercial/institutional incinerators with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through urea based selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	EPA 2017, EPA 2016b, Pechan 2006
NonEGU Point	By-Product Coke Mfg; Oven Underfiring	NSNCRCMOU	Selective Non-Catalytic Reduction	60	\$2,844		This control applies to dry-process cement manufacturing with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 1998a, EPA 1994e
NonEGU Point	Cement Manufacturing - Wet	NSNCRCMWT	Selective Non-Catalytic Reduction	50	\$1,335		This control applies to all by-product coke manufacturing operations with oven underfiring and uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through urea based selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	EPA 2016b, EPA 2017, Pechan 2006
NonEGU Point	External Combustion Boilers, Elec Gen, Coal	NSNCRCEBC	Selective Non-Catalytic Reduction	40	\$1,642		This control applies to wet-process cement manufacturing with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls to wall fired (coal) utility boilers. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) with a nitrogen based reducing reagent, such as ammonia or urea, to reduce the NOx into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b).	EPA 2007b

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonEGU Point	External Combustion Boilers, Elec Gen, Dis Oil	NSNCRECBDO	Selective Non-Catalytic Reduction	50	\$5,838		This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls to wall fired (coal) utility boilers. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) with a nitrogen based reducing reagent, such as ammonia or urea, to reduce the NOx into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b).	EPA 2007b
NonEGU Point	External Combustion Boilers, Elec Gen, Res Oil and Solid Waste	NSNCRECBROSW	Selective Non-Catalytic Reduction	50	\$3,231		This control applies to distillate oil external combustion boilers. This control is the use of selective non-catalytic reduction add-on controls to wall fired (oil/gas) utility boilers for the reduction of NOx emissions. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) with a nitrogen based reducing reagent, such as ammonia or urea, to reduce the NOx into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b).	EPA 2007b
NonEGU Point	Ammonia - NG-Fired Reformers	NSNCRFRNG	Selective Non-Catalytic Reduction	50	NOX < 365 tpy: \$6,711 NOX > 365 tpy: \$2,723		This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 1998a, EPA 2002b, EPA 1994d
NonEGU Point	Ammonia - Oil-Fired Reformers	NSNCRFROL	Selective Non-Catalytic Reduction	50	NOX < 365 tpy: \$4,474 NOX > 365 tpy: \$1,821		This control applies to ammonia production natural gas fired reformers with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 2006
NonEGU Point	ICI Boilers - Coal	NSNCRICBC	Selective Non-Catalytic Reduction	35	\$8,410		This control applies to ammonia production natural gas fired reformers with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). SNCR operates in the upper furnace region of the boiler at a temperature between 1600 to 2100 F (MACTEC 2005b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2017, EPA 2018, ERG 2019
<p>A SNCR will impose an energy impact on the host boiler. The losses attributable to this technology include: compressor power (air atomization/mixing), steam (if steam atomization/mixing), dry gas loss (air injection into furnace), and water evaporation loss (NESCAUM 2009).</p>								

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonEGU Point	ICI Boilers - Gas	NSNCRICBG	Selective Non-Catalytic Reduction	35	\$11,071		<p>This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). SNCR operates in the upper furnace region of the boiler at a temperature between 1600 to 2100 F (MACTEC 2005b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>A SNCR will impose an energy impact on the host boiler. The losses attributable to this technology include: compressor power (air atomization/mixing), steam (if steam atomization/mixing), dry gas loss (air injection into furnace), and water evaporation loss (NESCAUM 2009).</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2017, EPA 2018, ERG 2019
NonEGU Point	ICI Boilers - Oil	NSNCRICBO	Selective Non-Catalytic Reduction	35	\$9,537		<p>This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). SNCR operates in the upper furnace region of the boiler at a temperature between 1600 to 2100 F (MACTEC 2005b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>A SNCR will impose an energy impact on the host boiler. The losses attributable to this technology include: compressor power (air atomization/mixing), steam (if steam atomization/mixing), dry gas loss (air injection into furnace), and water evaporation loss (NESCAUM 2009).</p>	Bodnarik 2011, MACTEC 2005b, EPA 2000e, OTC-LADCO 2010, NESCAUM 2009, EPA 2017, EPA 2018, ERG 2019
NonEGU Point	Industrial Incinerators, Municipal Waste Combustors	NSNCRIMWC	Selective Non-Catalytic Reduction	45	\$1,960		<p>This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>This control applies to industrial incinerators IC boilers with uncontrolled NOx emissions greater than 10 tons per year.</p>	Pechan 1998a, EPA 2002b, Radian 1994
NonEGU Point	Iron & Steel Mills - Annealing	NSNCRISAN	Selective Non-Catalytic Reduction	60	\$2,844		<p>This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>This control applies to industrial incinerators IC boilers with uncontrolled NOx emissions greater than 10 tons per year.</p>	Pechan 1998a, EPA 1993a, EPA 1994e, EPA 2002b
NonEGU Point	Medical Waste Incinerators	NSNCRMWIN	Selective Non-Catalytic Reduction	45	\$7,821		<p>This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.</p> <p>This control applies to iron and steel mill annealing operations with uncontrolled NOx emissions greater than 10 tons per year.</p>	Pechan 1998a, EPA 2002b, STAPPA-ALAPCO 1994
							<p>This control applies to medical waste incinerators with uncontrolled NOx emissions greater than 10 tons per year.</p>	

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NonEGU Point	Space Heaters - Distillate Oil	NSNCRSHDO	Selective Non-Catalytic Reduction	50	NOx < 365 tpy: \$8,047 NOx > 365 tpy: \$3,278		This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 1998a, EPA 1994d
NonEGU Point	Space Heaters - Natural Gas	NSNCRSHNG	Selective Non-Catalytic Reduction	50	NOx < 365 tpy: \$6,711 NOx > 365 tpy: \$2,723		This control applies to distillate oil-fired space heaters with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 1998a, EPA 1994d
NonEGU Point	Solid Waste Disp;Gov;Other Incin;Sludge	NSNCRSWIN	Selective Non-Catalytic Reduction	45	\$1,960		This control applies to natural gas fired space heaters with uncontrolled NOx emissions greater than 10 tons per year. This control is the reduction of NOx emission through selective non-catalytic reduction add-on controls. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b). Ammonia can be utilized in either aqueous or anhydrous form. Anhydrous ammonia is a gas at atmospheric pressure and normal temperatures. There are safety issues with the use of anhydrous ammonia, as it must be transported and stored under pressure (EPA 2002b). Aqueous ammonia is generally transported and stored at a concentration of 29.4% ammonia in water. Urea based systems have several advantages, including several safety aspects. Urea is a nontoxic, less volatile liquid that can be stored and handled more safely than ammonia. Urea solution droplets can penetrate farther into the flue gas when injected into the boiler, enhancing mixing (EPA 2002b). Because of these advantages, urea is more commonly used than ammonia in large boiler applications.	Pechan 1998a, EPA 2002b, Radian 1994
EGU	Utility Boiler - Coal/Tangential	NSNCRUBCTx	Selective Non-Catalytic Reduction	25	25 MW < DC < 99 MW: \$3,470 100 MW < DC < 299 MW: \$2,821 300 MW < DC < 499 MW: \$2,644 500 MW < DC < 699 MW: \$2,546 DC > 700 MW: \$2,447		This control applies to solid waste disposal operations with uncontrolled NOx emissions greater than 10 tons per year. This control is the use of selective non-catalytic reduction add-on controls to reduce NOx emissions from tangentially coal-fired utility boilers. SNCR controls are post-combustion control technologies based on the chemical reduction of nitrogen oxides (NOx) with a nitrogen based reducing reagent, such as ammonia or urea, to reduce the NOx into molecular nitrogen (N2) and water vapor (H2O). SNCR is the reduction of NOx in flue gas to N2 and water vapor. This reduction is done with a nitrogen based reducing reagent, such as ammonia or urea. The reagent can react with a number of flue gas components. However, the NOx reduction reaction is favored for a specific temperature range and in the presence of oxygen (EPA 2002b). Both ammonia and urea are used as reagents. The cost of the reagent represents a large part of the annual costs of an SNCR system. Ammonia is generally less expensive than urea. However, the choice of reagent is also based on physical properties and operational considerations (EPA 2002b).	EPA 2006g, EPA 2017, EPA 2013, SRA 2016, EPA 2018
NonEGU Point	Gas Turbines - Natural Gas	NSTINGTNG	Steam Injection	80	DC > 26 MW: \$723 DC < 26 MW: \$2,443 DC < 26 MW: \$1,186		This control applies to bituminous/subbituminous coal-fired electricity generation sources, including sources with atmospheric fluidized bed combustion. This control is the use of steam injection to reduce NOx emissions.	Pechan 1998a, ERG 2000, EPA 1993b, DOE 1999, EPA 2018, RTI 2014
NonEGU Point	Adipic Acid Manufacturing	NTHRDADMF	Thermal Reduction	81	\$728		This control applies to small (3.3 MW to 34.4MW) natural gas-fired gas turbines with uncontrolled NOx emissions greater than 10 tons per year. Steam is injected into the gas turbine, reducing the temperatures in the NOx-forming regions. The steam can be injected into the fuel, the combustion air or directly into the combustion chamber (ERG 2000).	Pechan 2006
NonEGU Point	Gas Turbines - Natural Gas	NWTINGTNG	Water Injection	72	DC > 34.4 MW: \$1,055 DC < 34.4 MW: \$2,588 DC < 34.4 MW: \$1,446		This control is the use of water injection to reduce NOx emissions. This control applies to small (3.3 MW to 34.4MW) natural gas-fired gas turbines with uncontrolled NOx emissions greater than 10 tons per year. Water is injected into the gas turbine, reducing the temperatures in the NOx-forming regions. The water can be injected into the fuel, the combustion air or directly into the combustion chamber (ERG 2000).	Pechan 1998a, ERG 2000, EPA 1993b, DOE 1999, EPA 2018, RTI 2014

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonPoint	Beef Cattle Feedlots	PCATFWAT	Watering	50	\$532	PM2.5 (25%)	Control of fugitive dust emissions from agricultural (cattle) feedlots is most often performed by watering from either stationary sprinklers or from water trucks. This control is applicable to beef cattle feedlots.	Pechan 2006, Pechan 1998x, Peters 1977

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonPoint	Small Boilers	PANTUSMBLRxx	Annual tune-up at up to 25% RP	34	\$7,747		Annual tune-ups for small boilers at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Small Boilers	PAUDSMBLRxx	Energy audit at up to 25% RP	15	\$12,215		Energy audits for small boilers at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Fireplaces, Hydronic Heaters, Wood Stoves	PBBFPHHWSxx	Curtailement Program, aka Burn Ban at up to 25% RP	75	\$9,995	CO (75%), CO2 (75%), VOC (75%)	State and local air quality agencies forecast next day air quality levels. When it is expected to be near or above the 24-hr PM2.5 NAAQS, limited (e.g., wood pellet only) or full curtailement of wood burning is required. A public awareness campaign and enforcement are critical. Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Small Boilers	PBITUSMBLRxx	Biennial tune-up at up to 25% RP	22	\$5,988		Biennial tune-ups for small boilers at up to 25% RP	HARC 2015, GDIT 2020a
Fires	Household burning	PCHIPHB	Substitute chipping for burning	50	\$5,060		This control is the adoption of chipping rather than burning for household burning to reduce PM2.5 emissions.	EPA 2007x
Fires	Open burning	PCHIPOB	Substitute chipping for burning	100	\$5,060		This control is the adoption of chipping rather than burning for open burning to reduce PM2.5 emissions.	EPA 2007x
NonPoint	Commercial Cooking	PCOCHRBxx	Catalytic oxidizers at up to 25% RP	83	\$7,601		Catalytic oxidizers (up to 25% RP) are the most common control option for conveyor chain driven charbroilers. These controls are not effective with underfired charbroilers, deep fat fryers, griddles or other cooking devices because the temperatures of the exhaust heat are too low to create the catalytic process required.	HARC 2015, GDIT 2020a
NonPoint	Construction Activities	PCSCONSTxx	Chemical Stabilizer at up to 25% RP	84	\$2,845,176		Apply chemical stabilizers to up to 25% of unpaved roads	HARC 2015, GDIT 2020a
NonPoint	Unpaved Roads	PCSUNPAVEDxx	Chemical Stabilizer at up to 25% RP	84	\$31,478		Apply chemical stabilizers to up to 25% of unpaved roads	HARC 2015, GDIT 2020a
NonPoint	Fireplaces	PCTGLGFPLxx	Convert to Gas Logs at up to 25% RP	100	\$12,146	CO (100%), CO2 (100%), VOC (100%)	Incentives by various air districts in CA have helped retrofit thousands of open fireplaces to gas log sets. In addition to vented gas log sets, the option exists to install vented gas stove inserts into a wood-burning fireplace. Unlike gas logs, which provide little heat, a gas stove insert can be an efficient and clean way to a heat a room. The cost per ton of PM2.5 reductions will likely be greater as gas stove inserts cost more than gas log sets. Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Construction Activities	PDCPCONSTxx	Dust Control Plan at up to 25% RP	25	\$379,557		Dust control plan at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Unpaved Roads	PDSUNPAVEDxx	Dust Suppressants at up to 25% RP	60	\$43,612		Apply dust suppressants to up to 25% of unpaved roads	HARC 2015, GDIT 2020a
NonPoint	Wood Stoves	PECWSWDSTVxx	EPA-certified wood stove at up to 25% RP	60	\$11,374	CO (60%), CO2 (60%), VOC (60%)	Implement a program and provide incentives to replace old uncertified wood stoves with new EPA-certified wood stoves. Education on proper wood stove use (e.g., burn only dry wood) and maintenance is critical. See for more info: http://www.epa.gov/burnwise . Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Fireplaces	PEP2QUFPLxx	EPA Phase 2 Qualified Units at up to 25% RP	70	\$10,490	CO (70%), CO2 (70%), VOC (70%)	If new fireplace construction is allowed, approve only EPA Phase 2 qualified models. Under the EPA Wood-burning Fireplace Program, cleaner wood burning fireplaces are qualified when their PM2.5 emissions are at or below the Phase 2 PM2.5 emissions level. For a list of Phase 2 qualified cleaner burning fireplaces, go to: http://www.epa.gov/burnwise/fireplacelist.html . Cost per ton value (\$9,500/ton) indicates value incremental cost of installing a Phase 2 qualified RWC appliance instead of a non-Phase 2 RWC appliance. Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Commercial Cooking	PESPCcxx	Electrostatic Precipitator at up to 25% RP	99	\$12,916		An ESP consists of a two stage process: First, the exhaust stream gets charged in the first stage; then the charged particles are then collected in second stage.	HARC 2015, GDIT 2020a
NonEGU Point	ICI Boilers and Heaters - Solid Fuels	PESPICCOAL	Electrostatic Precipitator-All Types	95	\$1,821		This measure includes all types of electrostatic precipitators (ESP). Cost and cost effectiveness values were developed for combustion processes using coal, petroleum coke or solid waste as the fuel source.	GDIT 2019
NonEGU Point	ICI Boilers and Heaters - Gas and Oil	PESPICGAS	Electrostatic Precipitator-All Types	95	\$17,524		This measure includes all types of electrostatic precipitators (ESP). Cost and cost effectiveness values were developed for combustion processes using natural gas, process gas, residual oil or distillate oil as the fuel source.	GDIT 2019
NonEGU Point	ICI Boilers and Heaters - Wood	PESPICWOOD	Electrostatic Precipitator-All Types	95	\$1,876		This measure includes all types of electrostatic precipitators (ESP). Cost and cost effectiveness values were developed for combustion processes using wood or bagasse as the fuel source.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 1.0 microns	PESPISIZE1	Electrostatic Precipitator-All Types	95	\$2,756		This measure includes all types of electrostatic precipitators (ESP). Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 1.0 microns.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 10.0 microns	PESPISIZE10	Electrostatic Precipitator-All Types	95	\$1,503		This measure includes all types of electrostatic precipitators (ESP). Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 10.0 microns.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 5.0 microns	PESPISIZE5	Electrostatic Precipitator-All Types	95	\$1,729		This measure includes all types of electrostatic precipitators (ESP). Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 5.0 microns.	GDIT 2019
NonEGU Point	ICI Boilers and Heaters - Solid Fuels	PFFICCOAL	Fabric Filter-All Types	99	\$1,570		This measure includes all types of fabric filters (FF). Cost and cost effectiveness values were developed for combustion processes using coal, petroleum coke or solid waste as the fuel source.	GDIT 2019
NonEGU Point	ICI Boilers and Heaters - Gas and Oil	PFFICGAS	Fabric Filter-All Types	99	\$5,366		This measure includes all types of fabric filters (FF). Cost and cost effectiveness values were developed for combustion processes using natural gas, process gas, residual oil or distillate oil as the fuel source.	GDIT 2019
NonEGU Point	ICI Boilers and Heaters - Wood	PFFICWOOD	Fabric Filter-All Types	99	\$905		This measure includes all types of fabric filters (FF). Cost and cost effectiveness values were developed for combustion processes using wood or bagasse as the fuel source.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 1.0 microns	PFFIPSIZE1	Fabric Filter-All Types	99	\$1,091		This measure includes all types of fabric filters (FF). Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 1.0 microns.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 10.0 microns	PFFIPSIZE10	Fabric Filter-All Types	99	\$1,168		This measure includes all types of fabric filters (FF). Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 10.0 microns.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 5.0 microns	PFFIPSIZE5	Fabric Filter-All Types	99	\$1,139		This measure includes all types of fabric filters (FF). Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 5.0 microns.	GDIT 2019

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
EGU	Utility Boilers - Coal	PFPPJUBCx	Fabric Filter (Pulse Jet Type)	99	25 MW < DC < 99 MW: \$3,210 100 MW < DC < 299 MW: \$2,608 300 MW < DC < 499 MW: \$2,373 500 MW < DC < 699 MW: \$2,228 DC > 700 MW: \$2,084	PM10 (99%)	This control is the addition of a pulse-jet cleaned fabric filter to reduce PM emissions from waste streams from coal-fired utility boilers. In a fabric filter, flue gas is passed through a tightly woven or felted fabric, collecting PM by sieving and other mechanisms. Particulate-laden gas flows into the filter bag from the outside to the inside. The particles collected on the outside drop into a hopper below the fabric filter. During pulse-jet cleaning, a short burst of high pressure air is injected into the bags, dislodging the dust cake. This control applies to electricity generation sources powered by pulverized dry-bottom and bituminous/subbituminous coal. In a fabric filter, flue gas is passed through a tightly woven or felted fabric, collecting PM by sieving and other mechanisms. Fabric filters may be in the form of sheets, cartridges, or bags, with many individual filter units together in a group. Bags are the most common type of filter. The dust cake that forms on the filter from the collected PM can significantly increase collection efficiency. (EPA 2000c) Pulse-jet cleaning of fabric filters is a relatively new type of fabric filter, as they have only been used for the past 30 years. This cleaning mechanism has grown in popularity because it can treat high dust loadings, operate at constant pressure drop, and occupy less space than other types of fabric filters (EPA 2000c). Particulate-laden gas flows into the bag. The gas flows from the outside to the inside of the bags, and then out the gas exhaust. The particles collected on the outside drop into a hopper below the fabric filter (EPA 1998b). During pulse-jet cleaning, a short burst of high pressure air is injected into the bags (EPA 1998b). The pulse is blown through a venturi nozzle at the top of the bags and establishes a shock wave that continues onto the bottom of the bag. The wave flexes the fabric dislodging the dust cake. There are several unique attributes of pulse-jet cleaning. The cleaning pulse is very brief allowing the flow of dusty gas to continue during cleaning. The bags not being cleaned continue to filter, taking on extra duty from the bags being cleaned (EPA 2000c). Pulse-jet cleaning is more intense and occurs with greater frequency than the other fabric filter cleaning methods. The cleaning dislodges nearly all of the dust cake each time the bag is pulsed. Pulse-jet filters, as a result, do not rely on a dust cake to provide filtration. Felted (non-woven) fabrics are used in these types of filters because they do not require a dust cake. Since bags cleaned by the pulse-jet method do not need to be isolated for cleaning, pulsejet cleaned fabric filters do not need extra compartments to maintain adequate filtration during cleaning. Also, because of the intense and frequent nature of the cleaning, they can treat higher gas flow rates with higher dust loadings. Consequently, fabric filters cleaned by the pulse-jet method can be smaller than other filters in the treatment of the same amount of gas and dust, making higher gas-to-cloth ratios achievable (EPA 1998b). Fabric filters are useful for collecting particles with resistivities either too low or too high for collection with electrostatic precipitators. Fabric filters are useful in controlling particulate matter less than or equal to 10 micrometers in diameter (PM10) and particulate matter less than or equal to 2.5 micrometers in diameter (PM2.5). Fabric filters may be good candidates for collecting fly ash from low-sulfur coals or containing high unburned carbon levels and are relatively difficult to collect with electrostatic precipitators. (EPA 2000c)	EPA 2000c, EPA 1996e, EPA 1998b, EPA 2013, SRA 2016
NonPoint	Paved Roads	PGBTPAVEDxx	Gravel bed trackout at up to 25% RP	46	\$614,870		Reduce silt from trackout by requiring 50 foot of gravel that is 3 inches deep	HARC 2015, GDIT 2020a
NonPoint	Unpaved Roads	PGVUNPAVEDxx	Apply Gravel at up to 25% RP	40	\$65,418		Apply 4 inches of gravel to up to 25% of unpaved roads	HARC 2015, GDIT 2020a
NonPoint	Commercial Cooking	PHEPACCCxx	HEPA filters at up to 25% RP	90	\$14,093		A series of filters that capture particles by interception, impaction or diffusion. The pre-filter takes out the coarser particles, the second filter is a disposable bag that collects smaller particles and the final filter collects finest particles.	HARC 2015, GDIT 2020a
NonPoint	Hydronic Heaters	PICHHHTTRxx	Install Cleaner Hydronic Heaters at up to 25% RP	90	\$817	CO (90%), CO2 (90%), VOC (90%)	If hydronic heaters are allowed, only allow EPA Phase 2 qualified models. A Partnership Agreement (PA) is in place between EPA and wood-burning hydronic heater manufacturers. Under this PA, cleaner burning hydronic heaters are qualified at or below the Phase 2 particulate emissions level. For a list of Phase 2 qualified hydronic heaters, go to: http://www.epa.gov/burnwise/owhlist.html . Cost per ton value (\$750/ton) indicates value incremental cost of installing a Phase 2 qualified RWC appliance instead of a non-Phase 2 RWC appliance. Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Hydronic Heaters	PIRDVSHTRxx	Install Retrofit Devices at up to 25% RP	60	\$1,082	CO (60%), CO2 (60%), VOC (60%)	Provide incentives to encourage the installation of hydronic heater retrofit devices. Retrofits may significantly reduce and even eliminate visible smoke emissions. This measure should be accompanied by education and outreach (e.g., burn only dry seasoned wood). Implement a program and provide incentives to replace old uncertified wood stoves with new EPA-certified wood stoves. Education on proper wood stove use (e.g., burn only dry wood) and maintenance is critical. Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Fireplaces	PIRDVCFPLxx	Install Retrofit Devices at up to 25% RP	70	\$10,490	CO (70%), CO2 (70%), VOC (70%)	Provide incentives to encourage use of fireplace retrofit devices. Under the EPA Wood-burning Fireplace Program, retrofit devices are qualified when their PM2.5 emissions are at or below the program Phase 2 PM2.5 emissions level. For a list of Phase 2 qualified retrofits, go to: http://www.epa.gov/burnwise/fireplacelist.html . Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Open Burning	PLNDFILBRN	Substitution of landfilling for open burning	75	\$5,060	PM10 (75%)	This control is the substitution of landfilling for open burning to reduce PM emissions.	EPA 2006e
NonPoint	Cooling Towers	PMPCOOLxx	Implement maintenance plan at up to 25% RP	36.9	\$12,211		Implement maintenance plan at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Cooling Towers	PNDECOOLxx	Install new drift eliminator at up to 25% RP	79	\$4,443		Install new drift eliminator at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Wood Stoves	PNGSTWDSTVxx	New gas stove or gas logs at up to 25% RP	99	\$8,272	CO (99%), CO2 (99%), VOC (99%)	Implement an incentive program to replace old, uncertified wood stoves with new gas stoves or gas logs. Incentives to switch to a wood pellet stove are another good option. See for more info: http://www.epa.gov/burnwise/how-to-guide.html . Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Paved Roads	PPGTPAVEDxx	Pipe grid trackout at up to 25% RP	80	\$985,122		Reduce silt from trackout by requiring pipe grid system that shakes the accumulated dirt and mud from trucks leaving construction sites.	HARC 2015, GDIT 2020a
NonPoint	Paved Roads	PPIPAVEDxx	Pave interior roads at up to 25% RP	42	\$177,259		Reduce silt from trackout by requiring 100 foot of paved road be installed.	HARC 2015, GDIT 2020a
Fires	Prescribed Burning	PPRBRNFULM	Increase Fuel Moisture	50	\$5,253	PM10 (50%)	Prescribed burning is defined as the intentional burning of forest and range lands. For forestry burning, increasing the fuel moisture will decrease particulate emissions by decreasing the amount of fuel burned. This control is applicable to prescribed burning for forest management. Decreasing PM emissions is accomplished by either removing lighter and drier fuels or burning in early spring when moisture levels are naturally higher. Emission reductions estimates range from 30 to more than 50 percent (EPA 1992a, Hardy 1997x). Reductions will vary significantly depending on a given area. Variation is based on current burn schedule and method, along with the characteristics of the material to be burned.	Pechan 2006, EPA 1992a, BLS 1994x, Hardy 1997x
NonPoint	Paved Roads	PPSPAIVEDxx	Pave existing shoulders at up to 25% RP	60	\$159,310		Construction of 4 foot paved or stabilized shoulders at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Unpaved Roads	PPVUNPAVEDxx	Pave Unpaved Roads at up to 25% RP	95	\$91,274		Pave up to 25% of unpaved roads	HARC 2015, GDIT 2020a
NonPoint	Cooling Towers	PRDECOOLxx	Replace existing drift eliminator at up to 25% RP	74	\$5,996		Replace existing drift eliminator at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Wood Stoves	PROVSWDSTVxx	Remove old wood stoves at up to 25% RP	70	\$5,889	CO (70%), CO2 (70%), VOC (70%)	Implement an incentive program (usually voluntary) where cash (e.g., \$250) is given in return for turning in a wood stove. Assumes up to 25% rule penetration.	EPA 2013b, GDIT 2020a
NonPoint	Commercial Cooking	PSBCCxx	Smokeless Broiler at up to 25% RP	53	\$7,751		The smokeless broiler is an alternative to traditional underfired broiler. Since it is not a direct flame broiler, it has fewer emissions.	HARC 2015, GDIT 2020a
NonPoint	Commercial Cooking	PSCCCxx	Add-on Scrubber at up to 25% RP	85	\$13,274		Add-on scrubbers can be placed on the exhaust vents of underfired broilers.	HARC 2015, GDIT 2020a

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NonPoint	Construction Activities	PSPCONSTxx	Sprinkler System for Soil Moisture at up to 25% RP	68.6	\$482,890		Sprinkler system to add water to increase soil moisture at up to 25% RP	HARC 2015, GDIT 2020a
NonPoint	Paved Roads	PTCDPAVEDxx	Trackout control devices at up to 25% RP	46	\$307,082		A device that removes the mud, dust, silt and other particles from vehicles and construction equipment as it is leaving a construction area but before it enters a paved road.	HARC 2015, GDIT 2020a
NonPoint	Construction Activities	PTRCONSTxx	Truck System for Soil Moisture at up to 25% RP	68.6	\$1,236,807		Water trucks to add water to increase soil moisture at up to 25% RP	HARC 2015, GDIT 2020a
NonEGU Point	ICI Boilers and Heaters - Solid Fuels	PVSICICOAL	Venturi Scrubber	90	\$1,234		This measure includes all types of dry and wet scrubbers. Cost and cost effectiveness values were developed for combustion processes using coal, petroleum coke or solid waste as the fuel source.	GDIT 2019
NonEGU Point	ICI Boilers and Heaters - Gas and Oil	PVSICIGAS	Venturi Scrubber	90	\$9,684		This measure includes all types of dry and wet scrubbers. Cost and cost effectiveness values were developed for combustion processes using natural gas, process gas, residual oil or distillate oil as the fuel source.	GDIT 2019
NonEGU Point	ICI Boilers and Heaters - Wood	PVSICIWOOD	Venturi Scrubber	90	\$1,279		This measure includes all types of dry and wet scrubbers. Cost and cost effectiveness values were developed for combustion processes using wood or bagasse as the fuel source.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 1.0 microns	PVSIPSIZE1	Venturi Scrubber	90	\$1,693		This measure includes all types of dry and wet scrubbers. Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 1.0 microns.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 10.0 microns	PVSIPSIZE10	Venturi Scrubber	90	\$1,102		This measure includes all types of dry and wet scrubbers. Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 10.0 microns.	GDIT 2019
NonEGU Point	Generic Industrial Processes - MMD of 5.0 microns	PVSIPSIZE5	Venturi Scrubber	90	\$1,161		This measure includes all types of dry and wet scrubbers. Cost and cost effectiveness values were developed for industrial processes using a generic particle size distribution with a mass mean diameter of 5.0 microns.	GDIT 2019
NonPoint	Unpaved Roads	PWATUNPAVEDxx	Apply Water at up to 25% RP	18.1	\$713,640		Apply water to up to 25% of unpaved roads	HARC 2015, GDIT 2020a
NonPoint	Commercial Cooking	PWSCCxx	Wet scrubber at up to 25% RP	90	\$19,940		Wet scrubbers rely on an atomized stream of liquid to capture particulate pollutants from an exhaust stream.	HARC 2015, GDIT 2020a

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NonEGU Point	Petroleum Refinery Catalytic and Thermal Cracking Units	SCATPETCRK	Catalyst Additive	43	\$1,945		This control is the use of catalyst additives in fuel to reduce SO2 emissions from catalytic cracking and thermal cracking units at petroleum refineries.	MARAMA 2007, Eagleson et al. 2004x
NonPoint	Residential Nonpoint Source	SCHMADDDHOM	Chemical Additives to Waste	75	\$3,201		This control is the use of chemical additives to the waste produced by residential distillate oil combustion to control SO2 emissions.	Pechan 2006
NonEGU Point	ICI Boilers - Bituminous Coal	SDSICIBBC	Dry Scrubber	95.2	\$1,041		Dry Scrubber - In dry scrubbers (also called spray dryer absorbers), the flue gases are introduced into an absorbing tower (dryer) where the gases are contacted with a finely atomized alkaline slurry [usually a calcium-based sorbent such as Ca(OH)2 or CaO]. Acid gases are absorbed by the slurry mixture, and react to form solid salts. The heat of the flue gas is used to evaporate all the water droplets leaving a non-saturated (i.e. dry) flue gas exiting the absorber tower. The effect of cooling and humidifying the hot gas stream increases collection efficiency over simple dry injection. Since spray dryer absorbers only remove gases, a separate device is always required to remove particulates. The particulate control devices are generally fabric filters or electrostatic precipitators (ESPs). Reference: Costs developed using Air Pollution Control Cost Estimation Spreadsheet For Wet and Dry Scrubbers for Acid Gas Control (May 2021).	GDIT 2021, EPA 2021
NonEGU Point	ICI Boilers - Gas	SDSICIBG	Dry Scrubber	90	\$21,830		Dry Scrubber - In dry scrubbers (also called spray dryer absorbers), the flue gases are introduced into an absorbing tower (dryer) where the gases are contacted with a finely atomized alkaline slurry [usually a calcium-based sorbent such as Ca(OH)2 or CaO]. Acid gases are absorbed by the slurry mixture, and react to form solid salts. The heat of the flue gas is used to evaporate all the water droplets leaving a non-saturated (i.e. dry) flue gas exiting the absorber tower. The effect of cooling and humidifying the hot gas stream increases collection efficiency over simple dry injection. Since spray dryer absorbers only remove gases, a separate device is always required to remove particulates. The particulate control devices are generally fabric filters or electrostatic precipitators (ESPs).	ERG 2019
NonEGU Point	ICI Boilers - Oil	SDSICIBO	Dry Scrubber	90	\$17,969		Dry Scrubber - In dry scrubbers (also called spray dryer absorbers), the flue gases are introduced into an absorbing tower (dryer) where the gases are contacted with a finely atomized alkaline slurry [usually a calcium-based sorbent such as Ca(OH)2 or CaO]. Acid gases are absorbed by the slurry mixture, and react to form solid salts. The heat of the flue gas is used to evaporate all the water droplets leaving a non-saturated (i.e. dry) flue gas exiting the absorber tower. The effect of cooling and humidifying the hot gas stream increases collection efficiency over simple dry injection. Since spray dryer absorbers only remove gases, a separate device is always required to remove particulates. The particulate control devices are generally fabric filters or electrostatic precipitators (ESPs).	ERG 2019
NonEGU Point	ICI Boilers - Subbituminous Coal	SDSICIBSBC	Dry Scrubber	83.9	\$2,724		Dry Scrubber - In dry scrubbers (also called spray dryer absorbers), the flue gases are introduced into an absorbing tower (dryer) where the gases are contacted with a finely atomized alkaline slurry [usually a calcium-based sorbent such as Ca(OH)2 or CaO]. Acid gases are absorbed by the slurry mixture, and react to form solid salts. The heat of the flue gas is used to evaporate all the water droplets leaving a non-saturated (i.e. dry) flue gas exiting the absorber tower. The effect of cooling and humidifying the hot gas stream increases collection efficiency over simple dry injection. Since spray dryer absorbers only remove gases, a separate device is always required to remove particulates. The particulate control devices are generally fabric filters or electrostatic precipitators (ESPs). Reference: Costs developed using Air Pollution Control Cost Estimation Spreadsheet For Wet and Dry Scrubbers for Acid Gas Control (May 2021).	GDIT 2021, EPA 2021
NonPoint	Stationary Source Fuel Combustion	SFUELSFC	Fuel Switching	75	\$3,398	PM10 (80%), PM2.5 (80%)	This control transfers a home-heating oil fuel control to industrial boilers by substituting "red dye" distillate oil for high-sulfur fuel. Distillate has 500 ppm versus 2,500 to 3,000 ppm for high-sulfur diesel. The control applies to industrial stationary source distillate oil combustion sources.	EPA 2007x
NonEGU Point	ICI Boilers	SICIRIBxx	Increased Caustic Injection Rate for Existing Dry Injection Control	70	Cost per ton varies by flow rate and fuel type. Total cost is estimated using equation.		Increased Caustic Injection - This control measure involves an increase in the alkaline sorbent used for scrubbing flue gases to remove SO2. Depending on the application, the two most important sorbents are lime and sodium hydroxide (also known as caustic soda). Lime is typically used on large coal- or oil-fired boilers as found in power plants, as it is very much less expensive than caustic soda. The problem is that it results in a slurry being circulated through the scrubber instead of a solution. This makes it harder on the equipment. A spray tower is typically used for this application. The use of lime results in a slurry of calcium sulfite (CaSO3) that must be disposed of. Fortunately, calcium sulfite can be oxidized to produce by-product gypsum (CaSO4 * 2H2O) which is marketable for use in the building products industry. Caustic soda is limited to smaller combustion units because it is more expensive than lime, but it has the advantage that it forms a solution rather than a slurry. This makes it easier to operate. It produces a "spent caustic" solution of sodium sulfite/bisulfite (depending on the pH), or sodium sulfate that must be disposed of. This is not a problem in a kraft pulp mill for example, where this can be a source of makeup chemicals to the recovery cycle.	ERG 2015
EGU	Utility Boilers - Bituminous/Subbituminous Coal	SLSDUBCx	Lime Spray Dryer	92	25 MW < DC < 49 MW: \$1,956 50 MW < DC < 99 MW: \$1,956 100 MW < DC < 299 MW: \$1,457 300 MW < DC < 499 MW: \$1,292 500 MW < DC < 699 MW: \$1,236 DC > 700 MW: \$1,229		This control is the application of a Lime Spray Dryer to Utility Boilers to reduce SO2 emissions.	EPA 2013
EGU	Utility Boilers - Bituminous/Subbituminous Coal	SLSFOUBCx	Limestone Forced Oxidation	96	25 MW < DC < 99 MW: \$1,421 100 MW < DC < 299 MW: \$1,022 300 MW < DC < 499 MW: \$894 500 MW < DC < 699 MW: \$831 DC > 700 MW: \$761		This control is the application of a Lime Spray Dryer to Utility Boilers to reduce SO2 emissions.	EPA 2013
NonPoint	Residential Heating	SLSFRESHET	Low Sulfur Fuel	75	\$3,201	Nox (10%), PM10 (80%), PM2.5 (80%)	This measure is a switch from high-sulfur (2,500 ppm sulfur content) to low-sulfur (500 ppm) home heating oil for residential users.	NESCAUM 2005
NonEGU Point	NonEGUs	SPBSNONEGU	Packed Bed Scrubber	99	\$344		Packed Bed Scrubber - Packed tower absorbers are the most common approach to removing acidic gases from flue gas. The large wetted area provided by the packing makes it possible to achieve very high removal efficiencies at a relatively low capital and operating costs. Costs developed using Air Pollution Control Cost Estimation Spreadsheet For Wet and Dry Scrubbers for Acid Gas Control (May 2021).	GDIT 2021
NonEGU Point	Sulfur Recovery Plants - Elemental Sulfur (Claus: 2 Stage w/o control (92-95% removal))	SSRTGSRP95	Sulfur Recovery and/or Tail Gas Treatment	99.8	\$1,115		This control is the application of Sulfur recover and/or tail gas treatment controls to Sulfur Recovery Plant sources to reduce SO2 emissions. This control applies to uncontrolled elemental Sulfur Recovery plants (Claus: 3 Stage (92-95% removal)).	Pechan 2006
NonEGU Point	Sulfur Recovery Plants - Elemental Sulfur (Claus: 3 Stage w/o control (95-96% removal))	SSRTGSRP96	Sulfur Recovery and/or Tail Gas Treatment	99.8	\$1,115		This control is the application of Sulfur recover and/or tail gas treatment controls to Sulfur Recovery Plant sources to reduce SO2 emissions. This control applies to uncontrolled elemental Sulfur Recovery plants (Claus: 3 Stage (95-96% removal)).	Pechan 2006
NonEGU Point	Sulfur Recovery Plants - Elemental Sulfur (Claus: 3 Stage w/o control (96-97% removal))	SSRTGSRP97	Sulfur Recovery and/or Tail Gas Treatment	99.5	\$1,115		This control is the application of Sulfur recover and/or tail gas treatment controls to Sulfur Recovery Plant sources to reduce SO2 emissions. This control applies to uncontrolled elemental Sulfur Recovery plants (Claus: 3 Stage (96-97% removal)).	Pechan 2006

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonEGU Point	ICI Boilers - Bituminous Coal	SWSICIBBC	Wet Scrubber	95.2	\$1,267		<p>Wet Scrubber - This describes a variety of devices that remove pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants. The design of wet scrubbers or any air pollution control device depends on the industrial process conditions and the nature of the air pollutants involved. Inlet gas characteristics and dust properties (if particles are present) are of primary importance. Scrubbers can be designed to collect particulate matter and/or gaseous pollutants. The versatility of wet scrubbers allows them to be built in numerous configurations, all designed to provide good contact between the liquid and polluted gas stream.</p> <p>Wet scrubbers remove dust particles by capturing them in liquid droplets. The droplets are then collected, the liquid dissolving or absorbing the pollutant gases. Any droplets that are in the scrubber inlet gas must be separated from the outlet gas stream by means of another device referred to as a mist eliminator or entrainment separator (these terms are interchangeable). Also, the resultant scrubbing liquid must be treated prior to any ultimate discharge or being reused in the plant. A wet scrubber's ability to collect small particles is often directly proportional to the power input into the scrubber. Low energy devices such as spray towers are used to collect particles larger than 5 micrometers. To obtain high efficiency removal of 1 micrometer (or less) particles generally requires high energy devices such as venturi scrubbers or augmented devices such as condensation scrubbers. Additionally, a properly designed and operated entrainment separator or mist eliminator is important to achieve high removal efficiencies. The greater the number of liquid droplets that are not captured by the mist eliminator the higher the potential emission levels.</p> <p>Wet scrubbers that remove gaseous pollutants are referred to as absorbers. Good gas-to-liquid contact is essential to obtain high removal efficiencies in absorbers. A number of wet scrubber designs are used to remove gaseous pollutants, with the packed tower and the plate tower being the most common. If the gas stream contains both particle matter and gases, wet scrubbers are generally the only single air pollution control device that can remove both pollutants. Wet scrubbers can achieve high removal efficiencies for either particles or gases and, in some instances, can achieve a high removal efficiency for both pollutants in the same system. However, in many cases, the best operating conditions for particles collection are the poorest for gas removal.</p>	GDIT 2021, EPA 2021
NonEGU Point	ICI Boilers - Gas	SWSICIBG	Wet Scrubber	95	\$4,825	PM10 (50%), PM2.5 (50%)	<p>Wet Scrubber - This describes a variety of devices that remove pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants. The design of wet scrubbers or any air pollution control device depends on the industrial process conditions and the nature of the air pollutants involved. Inlet gas characteristics and dust properties (if particles are present) are of primary importance. Scrubbers can be designed to collect particulate matter and/or gaseous pollutants. The versatility of wet scrubbers allows them to be built in numerous configurations, all designed to provide good contact between the liquid and polluted gas stream.</p> <p>Wet scrubbers remove dust particles by capturing them in liquid droplets. The droplets are then collected, the liquid dissolving or absorbing the pollutant gases. Any droplets that are in the scrubber inlet gas must be separated from the outlet gas stream by means of another device referred to as a mist eliminator or entrainment separator (these terms are interchangeable). Also, the resultant scrubbing liquid must be treated prior to any ultimate discharge or being reused in the plant. A wet scrubber's ability to collect small particles is often directly proportional to the power input into the scrubber. Low energy devices such as spray towers are used to collect particles larger than 5 micrometers. To obtain high efficiency removal of 1 micrometer (or less) particles generally requires high energy devices such as venturi scrubbers or augmented devices such as condensation scrubbers. Additionally, a properly designed and operated entrainment separator or mist eliminator is important to achieve high removal efficiencies. The greater the number of liquid droplets that are not captured by the mist eliminator the higher the potential emission levels.</p> <p>Wet scrubbers that remove gaseous pollutants are referred to as absorbers. Good gas-to-liquid contact is essential to obtain high removal efficiencies in absorbers. A number of wet scrubber designs are used to remove gaseous pollutants, with the packed tower and the plate tower being the most common. If the gas stream contains both particle matter and gases, wet scrubbers are generally the only single air pollution control device that can remove both pollutants. Wet scrubbers can achieve high removal efficiencies for either particles or gases and, in some instances, can achieve a high removal efficiency for both pollutants in the same system. However, in many cases, the best operating conditions for particles collection are the poorest for gas removal.</p>	ERG 2019
NonEGU Point	ICI Boilers - Oil	SWSICIBO	Wet Scrubber	95	\$4,184	PM10 (94%), PM2.5 (94%)	<p>Wet Scrubber - This describes a variety of devices that remove pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants. The design of wet scrubbers or any air pollution control device depends on the industrial process conditions and the nature of the air pollutants involved. Inlet gas characteristics and dust properties (if particles are present) are of primary importance. Scrubbers can be designed to collect particulate matter and/or gaseous pollutants. The versatility of wet scrubbers allows them to be built in numerous configurations, all designed to provide good contact between the liquid and polluted gas stream.</p> <p>Wet scrubbers remove dust particles by capturing them in liquid droplets. The droplets are then collected, the liquid dissolving or absorbing the pollutant gases. Any droplets that are in the scrubber inlet gas must be separated from the outlet gas stream by means of another device referred to as a mist eliminator or entrainment separator (these terms are interchangeable). Also, the resultant scrubbing liquid must be treated prior to any ultimate discharge or being reused in the plant. A wet scrubber's ability to collect small particles is often directly proportional to the power input into the scrubber. Low energy devices such as spray towers are used to collect particles larger than 5 micrometers. To obtain high efficiency removal of 1 micrometer (or less) particles generally requires high energy devices such as venturi scrubbers or augmented devices such as condensation scrubbers. Additionally, a properly designed and operated entrainment separator or mist eliminator is important to achieve high removal efficiencies. The greater the number of liquid droplets that are not captured by the mist eliminator the higher the potential emission levels.</p> <p>Wet scrubbers that remove gaseous pollutants are referred to as absorbers. Good gas-to-liquid contact is essential to obtain high removal efficiencies in absorbers. A number of wet scrubber designs are used to remove gaseous pollutants, with the packed tower and the plate tower being the most common. If the gas stream contains both particle matter and gases, wet scrubbers are generally the only single air pollution control device that can remove both pollutants. Wet scrubbers can achieve high removal efficiencies for either particles or gases and, in some instances, can achieve a high removal efficiency for both pollutants in the same system. However, in many cases, the best operating conditions for particles collection are the poorest for gas removal.</p>	ERG 2019

**Point & NonPoint SO2
Menu of Control Measures**
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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonEGU Point	ICI Boilers - Subbituminous Coal	SWSICIBSBC	Wet Scrubber	83.9	\$3,784		<p>Wet Scrubber - This describes a variety of devices that remove pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants. The design of wet scrubbers or any air pollution control device depends on the industrial process conditions and the nature of the air pollutants involved. Inlet gas characteristics and dust properties (if particles are present) are of primary importance. Scrubbers can be designed to collect particulate matter and/or gaseous pollutants. The versatility of wet scrubbers allows them to be built in numerous configurations, all designed to provide good contact between the liquid and polluted gas stream.</p> <p>Wet scrubbers remove dust particles by capturing them in liquid droplets. The droplets are then collected, the liquid dissolving or absorbing the pollutant gases. Any droplets that are in the scrubber inlet gas must be separated from the outlet gas stream by means of another device referred to as a mist eliminator or entrainment separator (these terms are interchangeable). Also, the resultant scrubbing liquid must be treated prior to any ultimate discharge or being reused in the plant. A wet scrubber's ability to collect small particles is often directly proportional to the power input into the scrubber. Low energy devices such as spray towers are used to collect particles larger than 5 micrometers. To obtain high efficiency removal of 1 micrometer (or less) particles generally requires high energy devices such as venturi scrubbers or augmented devices such as condensation scrubbers. Additionally, a properly designed and operated entrainment separator or mist eliminator is important to achieve high removal efficiencies. The greater the number of liquid droplets that are not captured by the mist eliminator the higher the potential emission levels.</p> <p>Wet scrubbers that remove gaseous pollutants are referred to as absorbers. Good gas-to-liquid contact is essential to obtain high removal efficiencies in absorbers. A number of wet scrubber designs are used to remove gaseous pollutants, with the packed tower and the plate tower being the most common. If the gas stream contains both particle matter and gases, wet scrubbers are generally the only single air pollution control device that can remove both pollutants. Wet scrubbers can achieve high removal efficiencies for either particles or gases and, in some instances, can achieve a high removal efficiency for both pollutants in the same system. However, in many cases, the best operating conditions for particles collection are the poorest for gas removal.</p>	GDIT 2021, EPA 2021

**Point & NonPoint VOC
Menu of Control Measures**
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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonEGU Point	Flexible Package Printing	VAOXFPF	Add-on controls, work practices, and material reformulation/substitution	67	\$3,433		EPA issued a CTG for Flexible Package Printing in 2006 that includes recommended control techniques. EPA's recommended emission limits are based on the 1978 CTG for graphic arts (which included rotogravure printing and flexographic printing) and on the 1996 NESHAP. This CTG provides control recommendations for reducing VOC emissions from (1) inks, coatings, adhesives and (2) cleaning materials used in flexible packaging printing. EPA recommends applying the recommendations for operations that emit at least (1) 25 tpy of VOC from inks, and for operations that emit at least (2) 15 lb/day of VOC due to fountain solutions and cleaning materials (before consideration of controls). The approach to reducing VOC emissions from inks, coatings, and adhesives includes adding/improving add-on controls with an overall emission reduction of 65 to 80 percent (depending on the first installation date of the equipment) and material reformulation/substitution (low- and no-VOC inks, coatings, and adhesives) with an 80 percent overall emissions reduction level. The recommended approach to reduce VOC emissions from cleaning materials includes use of work practices (keeping solvent containers closed, conducting cleaning operations, conveying cleaning materials in closed containers, etc.)	EPA 2006c
NonEGU Point	Generic NonEGU	VCAGENVOC	Carbon Adsorber	99	\$1,349		This control measure and associated costs was developed based on EPA's Control Cost Manual, Section 3 - VOC Controls, Section 3.1 - VOC Recapture Controls, Chapter 1 - Carbon Adsorbers; and associated control cost calculation spreadsheet.	GDIT 2020b, EPA 2017
NonEGU Point	Generic NonEGU	VCOXGENVOC	Catalytic Oxidizer	99	\$2,335		This control measure and associated costs was developed based on EPA's Control Cost Manual, Section 3 - VOC Controls, Section 3.2 - VOC Destruction Controls, Chapter 2 - Incinerators and Oxidizers; and associated control cost calculation spreadsheet.	GDIT 2020b, EPA 2017
NonEGU Point	Miscellaneous Metal and Plastic Parts Coatings	VCTRMPPC	Coating Reformulation	35	\$2,155		In the 2008 EPA CTG for miscellaneous metal and plastic parts coatings three options were recommended for controlling VOC emissions: (1) VOC content limits for each coating category based on the use of low-VOC content coatings and specified application methods to achieve good transfer efficiency; (2) equivalent VOC emission rate limits based on the use of a combination of low-VOC coatings, specified application methods, and add-on controls; or (3) an overall VOC control efficiency of 90 percent for facilities that choose to use add-on controls instead of low-VOC Content coatings and specified application methods. EPA expects that in practice, facilities will choose the low-VOC coating materials alternative. In addition, EPA recommended work practices to further reduce VOC emissions from coatings as well as to minimize emissions from cleaning materials used in miscellaneous metal product and plastic part surface coating processes. The recommendations in this CTG are similar to the South Coast regulations governing miscellaneous metal product and plastic part surface coating operations, and Michigan Rule 336.1632.	EPA 2008a
NonEGU Point	Flat Wood Paneling Coatings	VLVMAFWPC	Low-VOC materials coatings and Add-On Controls	90	\$3,188		EPA issued a new CTG for flat wood paneling coating facilities in 2006. The 2006 CTG recommends emission limits for the inks, coatings and adhesives used by the flat wood paneling coating facilities and work practices for cleaning materials used. The low-VOC materials recommendation for inks, coatings and adhesives include an emission limit of 2.1 lbs. per gallon of materials. Should product performance requirements or other needs dictate the use of higher-VOC Coatings than this, a facility could choose to use add-on control equipment to meet an overall control efficiency of 90 percent. Add-on devices include oxidizers and solvent recovery systems. The CTG also recommends work practices for use in all flat wood paneling coating facilities meeting the 15 lb per day threshold. The new CTG emission limits for this source category are based on the rules in Placer County (Rule 238) and SCAQMD (Rule 1104) in California.	EPA 2006b
NonEGU Point	Paper Film and Foil Coatings	VLVMAFFC	Low-VOC coating materials and/or add-on controls	90	\$1,471		EPA issued a 2007 CTG for paper, film and foil coatings. Previous federal actions that affected this source category included a 1977 CTG for controlling VOC emissions from surface coating of paper, the 1983 NSPS for surface coating of pressure sensitive tape and labels (a subset of this category), and a 2002 NESHAP for paper and other web coating. EPA recommends applying the control recommendations for coatings only on individual paper, film and foil surface coating lines with the potential to emit at least 25 tpy of VOC from coatings, prior to controls. EPA recommends an overall VOC control efficiency of 90% as RACT for each coating line. This level of control is based on current rules in San Diego and Ventura air districts in California, as well as the NSPS. The CTG does not recommend the 95 percent control level that is currently required by the NESHAP and seven State's regulations.	EPA 2007f
NonEGU Point	Flat Wood Paneling Coatings	VLVMPWPC	Low-VOC materials coatings	60	\$2,329		EPA issued a new CTG for flat wood paneling coating facilities in 2006. The 2006 CTG recommends emission limits for the inks, coatings and adhesives used by the flat wood paneling coating facilities and work practices for cleaning materials used. The low-VOC materials recommendation for inks, coatings and adhesives include an emission limit of 2.1 lbs. per gallon of materials. The CTG also recommends work practices for use in all flat wood paneling coating facilities meeting the 15 lb per day threshold. The new CTG emission limits for this source category are based on the rules in Placer County (Rule 238) and SCAQMD (Rule 1104) in California.	EPA 2006b
NonEGU Point	Large Appliance Surface Coating	VLVMLASC	Low-VOC coating materials	30	\$613		In 2007, EPA issued a CTG for large appliance coatings. EPA developed this new CTG after considering the 1977 CTG, the 1982 NSPS, the 2002 NESHAP, and existing State and local VOC emission reduction approaches for this category. The new CTG applies to facilities with 15 lbs per day or more of VOC emissions from large appliance coating operations. There are two main sources of VOC emissions from large appliance coating operations: (1) evaporation of VOC from the coatings; and (2) evaporation of VOC from the cleaning materials. To control VOC emissions from large appliance coatings, EPA recommended three alternatives: (1) emission limits that can be achieved through the use of low-VOC coatings; (2) equivalent emission limits that can be achieved through the use of low-VOC coatings or a combination of coatings and add-on controls; and (3) an overall control efficiency of 90 percent for add-on controls. EPA expects that in practice, facilities will choose the low-VOC coating materials alternative. EPA recommends work practices to reduce VOC emissions. The recommendations in this CTG are similar to the South Coast regulations for this source category (SCAQMD Rule 1107).	EPA 2007d
NonEGU Point	Metal Furniture Coatings	VLVMMFC	Low-VOC coating materials	35	\$245		EPA issued a 2007 CTG for metal furniture coatings. Previous federal actions that affected this source category include a 1977 CTG, a 1982 NSPS and a 2003 NESHAP (Surface Coating of Metal Furniture). In the 2007 CTG, EPA recommended three alternatives: (1) emission limits that can be achieved through the use of low VOC Coatings; (2) equivalent emission limits that can be achieved through the use of low-VOC coatings and add-on controls, (3) an overall control efficiency of 90 percent for add-on controls. The low-VOC coatings recommendation consists of emission limits in terms of mass of VOC per volume of coating, excluding water and exempt compounds, as applied and the use of specified application methods. The equivalent emission limit recommendation consists of emission limits in terms of mass of VOC per volume of coating solids, as applied, and the use of specific add-on controls. EPA expects that in practice, facilities will choose the low-VOC coating materials alternative. The CTG recommendations are similar to the South Coast regulations governing metal furniture surface coating operations.	EPA 2007e
NonEGU Point	Miscellaneous Industrial Adhesives	VLVMMIA	Low VOC Adhesives and Improved Application Methods	64	\$322		This control is based on EPA's 2008 Control Techniques Guidelines for Miscellaneous Industrial Adhesives. It recommends 85 percent VOC reduction through the use of low-VOC content adhesives and specified application methods with good adhesive transfer efficiency; or through the use of a combination of low-VOC adhesives, specified application methods, and add-on controls. The control efficiency is not 85 percent because there are a number of exceptions for certain types of adhesives and adhesives primer application processes. Because the exceptions are for types of processes are at a sub-SCC level, the modeled reduction is lower than 85 percent.	EPA 2008c, EPA 1995b
NonEGU Point	Fabric Printing/ Coating and Dyeing	VPTEFPCD	Permanent Total Enclosure (PTE)	97	\$1,992		A permanent total enclosure (PTE) completely surrounds a source of emissions such that all VOC emissions are captured and contained for discharge to a control device. Fabric printing and coating is performed in the textile manufacturing industry in order to: prepare fiber and subsequently manufacture yarn, threads, braids, twine, and cordage; manufacture broadwoven fabrics, narrow woven fabrics, knit fabrics, and carpets and rugs from yarn; finish fiber, yarn, fabrics, and knit apparel; coat, waterproof, or otherwise treat fabrics; perform integrated manufacturing of knit apparel and other finished articles from yarn; and manufacture felt goods, lace goods, nonwoven fabrics, and miscellaneous textiles. The EPA evaluated VOC emission control options for the fabric printing and coating industry including the use of a PTE in conjunction with a thermal oxidizer in the MACT standard-setting process for this source category. The option presented here has applicability to fabric printing/coating processes that use "high" VOC content materials.	Pechan 2006

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Sector	Source Category	Control Measure Abbreviation	Emission Reduction Measure	Control Efficiency (%)	Cost Effectiveness (2018\$/ton reduced)	Other Pollutants Controlled	Description/Notes/Caveats	References
NonEGU Point	Metal Can Surface Coating	VP TENM CSC	Permanent Total Enclosure (PTE)	95	\$11,538		A permanent total enclosure (PTE) completely surrounds a source of emissions such that all VOC emissions are captured and contained for discharge to a control device. A metal can is defined as a usually cylindrical metal container, but governmental agencies and industry groups use differing criteria to identify cans including shape, materials, capacity, phase of product contained, and material thickness (gauge). Decorative tins, bottle caps and jar lids are also included in the can coating category since many of these items are coated on the same line where can coating takes place. Cans consist of can bodies and can ends. Metal can surface coating facilities include two-piece beverage can body facilities, two-piece food can body facilities, one-piece aerosol can body facilities, sheetcoating facilities, three-piece food can body assembly facilities, three-piece non-food can body assembly facilities, and end lining facilities. EPA evaluated VOC emission control options for the two-piece beverage can, two-piece food can and sheetcoating facilities using a PTE in conjunction with a thermal oxidizer in the MACT standard-setting process for this source category. The option presented here has applicability to processes that use "high" VOC content materials (solvent-borne materials).	Pechan 2006
NonEGU Point	Metal Furniture Surface Coating	VP TENMF SC	Permanent Total Enclosure (PTE)	95	\$28,339		A permanent total enclosure (PTE) completely surrounds a source of emissions such that all VOC emissions are captured and contained for discharge to a control device. Metal furniture surface coating operations involve: surface preparation of the metal furniture prior to coating application; preparation of a coating for application (e.g., mixing in additives, dissolving resins); application of a coating to metal furniture; flashoff, drying, and curing following coating application; cleaning of equipment used in the coating application operation; storage of coatings, additives, and cleaning materials; conveyance of coatings, additives, and cleaning materials from storage areas to mixing areas or to coating application areas, either manually or by automated means; and handling and conveyance of waste materials generated by the surface coating operation. The EPA evaluated VOC emission control options for the metal furniture coating industry including the use of a PTE in conjunction with a thermal oxidizer in the MACT standard-setting process for this source category. The option presented here has applicability to processes that use "high" VOC content materials (solvent-borne materials).	Pechan 2006
NonEGU Point	Paper and Other Web Coating	VP TENPO WC	Permanent Total Enclosure (PTE)	95	\$2,204		A permanent total enclosure (PTE) completely surrounds a source of emissions such that all VOC emissions are captured and contained for discharge to a control device. The paper and other web coating category includes the surface coating of pressure sensitive tapes and labels, photographic film, industrial and decorative laminates, flexible vinyl products, flexible packaging, abrasive products and folding paperboard boxes (flexible packaging, flexible vinyl products and folding paperboard boxes emissions are also treated in the paper printing source category). The EPA evaluated VOC emission control options for the paper and other web coating industry including the use of a PTE in conjunction with a regenerative thermal oxidizer in the MACT standard-setting process for this source category.	Pechan 2006
NonEGU Point	Product and Package Rotogravure Printing	VP TENPP RS	Permanent Total Enclosure (PTE)	96	\$20,459		A permanent total enclosure (PTE) completely surrounds a source of emissions such that all VOC emissions are captured and contained for discharge to a control device. Product and packaging rotogravure includes folding cartons, flexible packaging, labels and wrappers, gift wraps, wall coverings, vinyl printing, decorative laminates, floor coverings, tissue products and miscellaneous specialty products such as cigarette tipping paper. The EPA evaluated VOC emission control options for the Product and Package rotogravure printing industry including the use of a PTE in conjunction with a solvent concentrator in the MACT standard-setting process for this source category.	Pechan 2006
NonEGU Point	Generic NonEGU	VR TOGEN VOC	Regenerative Thermal Oxidizer	99	\$2,581		This control measure and associated costs was developed based on EPA's Control Cost Manual, Section 3 - VOC Controls, Section 3.2 - VOC Destruction Controls, Chapter 2 - Incinerators and Oxidizers; and associated control cost calculation spreadsheet.	GDIT 2020b, EPA 2017
NonEGU Point	Fiberglass Boat Manufacturing	VS OLSFB M	Solvent substitution, non-atomized resin application methods	35	\$5,149		EPA issued a CTG during 2008 that provides control recommendations for reducing VOC emissions from the use of gel coats, resins, and materials used to clean application equipment in fiberglass boat manufacturing operations. The CTG recommends the use of low-VOC content (monomer and non-monomer VOC) resin and gel coats with specified application methods. The CTG recommends the use of covers on mixing containers to further reduce VOC emissions from gel coats and resins. The CTG also recommends the use of low-VOC and low vapor pressure cleaning materials. Because the CTG recommendations are based on the 2001 NESHAP for boat manufacturing, those facilities that are major sources of HAP are already complying with the 2001 NESHAP and have already adopted these control measures. Because the 2001 NESHAP does not apply to area sources, area source fiberglass boat manufacturing facilities are not currently required to implement the measures provided in the NESHAP and recommended in the CTG. There are boat manufacturing facilities in ozone nonattainment areas that meet the applicability threshold in the CTG and would provide VOC emission reductions when the CTG recommended controls are applied. These control approaches are recommended for all fiberglass boat manufacturing facilities where total actual VOC emissions from all fiberglass boat manufacturing operations are equal to or exceed 15 lb/day.	EPA 2008b
NonEGU Point	Miscellaneous Industrial Adhesives	VS OLSM IA	Solvent Substitution	64	\$325		EPA issued a CTG for miscellaneous industrial adhesives in 2008. This provides information for states to consider in determining RACT. EPA's recommended emission limits are based on the OTC Model Rule for Adhesives and Sealants. The emission limits in the OTC rule were the same as California ARB RACT standards, which were based on numerous California district rules. EPA recommends that the control approaches suggested apply to each miscellaneous industrial adhesive application process at a facility where the total actual VOC emissions from all application processes, including related cleaning activities at that facility are equal to or exceed 15 lbs per day before consideration of controls. EPA recommends specific VOC emission limits based on application processes. There are two options for achieving recommended emission limits: (1) through the use of low-VOC content adhesives and specified application methods with good adhesive transfer efficiency; or (2) through the use of a combination of low-VOC adhesives, specified methods and add-on controls. As an alternative to the emission limits, an overall 85 percent control efficiency is recommended. EPA expects that in practice, facilities will choose the low-VOC materials alternative.	EPA 2008c
NonEGU Point	Generic NonEGU	VVRUGEN VOC	Vapor Recovery Unit	97	\$25,356		This control measure and associated costs was developed based on EPA's Control Cost Manual, Section 3 - VOC Controls, Section 3.1 - VOC Recapture Controls, Chapter 2 - Refrigerated Condensers; and associated control cost calculation spreadsheet.	GDIT 2020b, EPA 2017

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