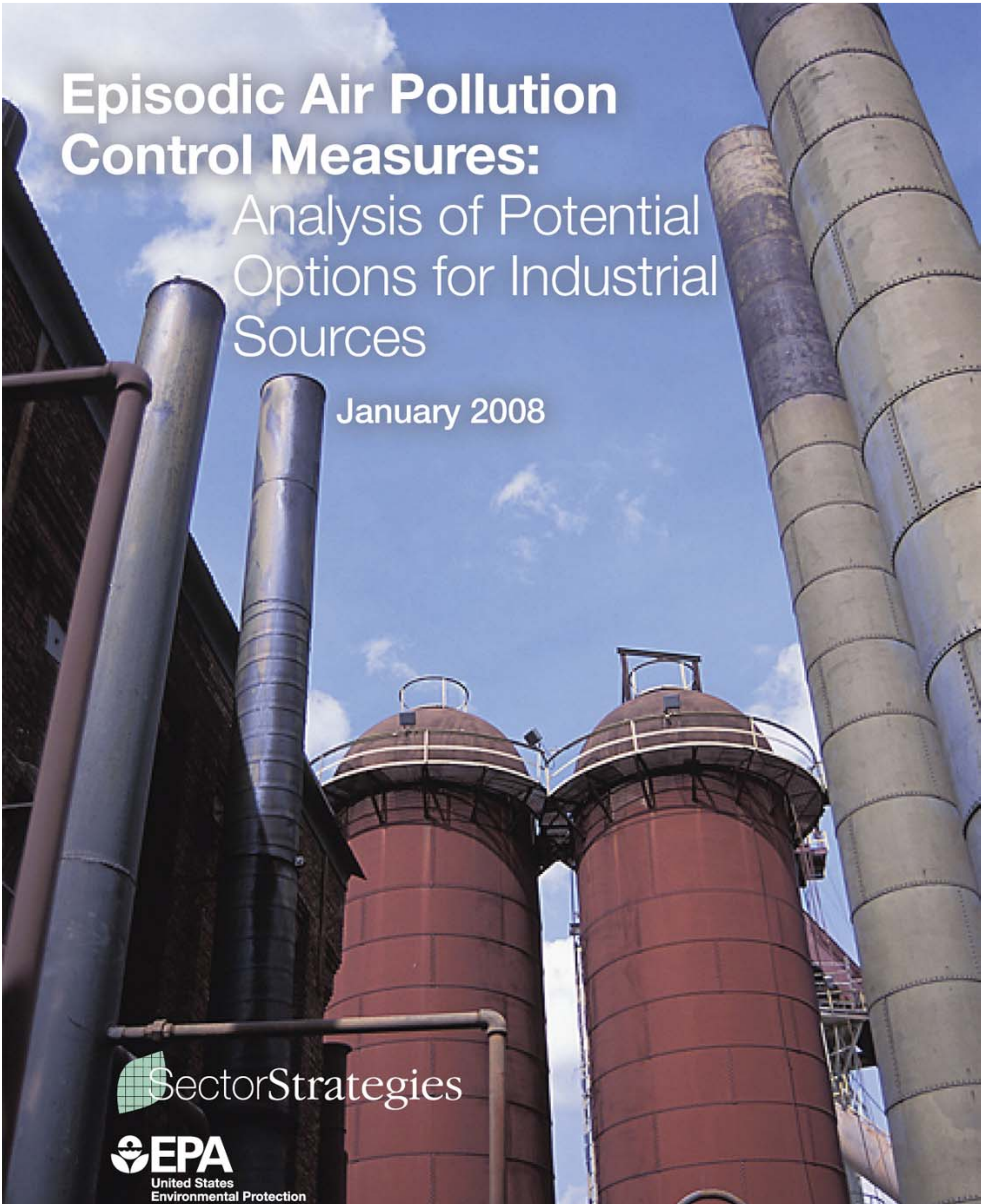
Episodic Air Pollution Control Measures:

Analysis of Potential Options for Industrial Sources

January 2008



SectorStrategies

EPA
United States
Environmental Protection
Agency

This page deliberately left blank.

Episodic Air Pollution Control Measures:

Analysis of Potential Options for Industrial Sources

Report

January 2008

Prepared for:
U.S. Environmental Protection Agency
Office of Policy, Economics and Innovations
Sector Strategies Division
Work Assignment Manager: Barry Elman
elman.barry@epa.gov

Prepared by:
ICF International
9300 Lee Highway
Fairfax, VA 22031
(703) 934-3000
Project Manager: Bansari Saha
bsaha@icfi.com

Table of Contents

List of Exhibits

List of Acronyms

AF&PA	American Forest & Paper Association
AIRS	Aerometric Information Retrieval System (EPA)
AISI	American Iron and Steel Institute
AQM	Air Quality Management (subcommittee of EPA's Clean Air Act Advisory Council)
BOF	Basic oxygen furnace
Btu	British thermal units
CAA	Clean Air Act
CAAAC	Clean Air Act Advisory Council (EPA)
CAP	Criteria air pollutant
CKD	Cement kiln dust
CO	Carbon monoxide
DOE	US Department of Energy
EAF	Electric arc furnace
EPA	US Environmental Protection Agency
ESP	Electrostatic precipitator
FGD	Flue gas desulfurization
GIS	Geographic Information System
lb	Pound
LPG	Liquified petroleum gas
MMBtu	Million Btu
NAAQS	National Ambient Air Quality Standard
NAICS	North American Industrial Classification System
NEI	National Emissions Inventory (EPA)
NESCAUM	Northeast States for Coordinated Air Use Management
NESHAP	National Emissions Standard for Hazardous Air Pollutant
NH_3	Ammonia
NOx	Nitrogen oxides
O&M	Operation and maintenance
OAQPS	Office of Air Quality Planning and Standards (EPA)
OPEI	Office of Policy, Economics, and Innovation (EPA)
PCA	Portland Cement Association
PM	Particulate matter
PM2.5	Particulate matter that is 2.5 micrometers or smaller in size
PRB	Powder River Basin (coal)
SCAQMD	South Coast Air Quality Management District
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SNCR	Selective Non-Catalytic Reduction
SO_2	Sulfur dioxide
SSD	Sector Strategies Division (EPA)
TDF	Tire derived fuel
TRI	Toxics Release Inventory (EPA)
VOC	Volatile organic compound

Acknowledgements

We would like to thank the following individuals for providing technical information on the industry sectors, pointing us to other experts and sources of information, and reviewing sections of this report: Timothy Hunt of the American Forest & Paper Association; Arun Someshwar and John Pinkerton of the National Council for Air and Stream Improvement; Lawrence Kavanagh and Bruce Steiner of the American Iron & Steel Institute; Paul Sheehan of the Sponseller Group, Inc. (Chair of the Environmental Technology Operating Committee of the Association for Iron and Steel Technology); and Tom Carter of the Portland Cement Association. Full responsibility for the contents of this report remains, however, with ICF International and EPA.

Executive Summary

The Air Quality Management (AQM) Subcommittee of EPA's Clean Air Act Advisory Committee (CAAAC) recently recommended expanding the use of episodic control measures to help attain and maintain National Ambient Air Quality Standards (NAAQS) in areas where all reasonable continuous (i.e., year-round) and seasonal control measures have already been required.[1] Episodic control measures may be particularly useful in areas that are at risk of exceeding the 8-hour ozone NAAQS and/or the 24-hour fine particle (PM2.5) NAAQS only on a limited number of days each year.

This study seeks to help EPA, states, communities, and other stakeholders assess the potential use of episodic control measures by industrial sources. For purposes of this analysis, episodic control measures are defined as measures that could be implemented intermittently, on 24-hours advance notice, and for a total of up to 10 continuous or non-continuous days per year, to help attain or maintain the short-term NAAQS for ozone or PM2.5.

Three industry sectors were selected as case studies for this analysis: pulp and paper; iron and steel; and cement. We researched specific technological options for achieving additional emission reductions on an episodic basis within the three selected sectors and assessed the implications of these options for emission sources in other industry sectors. The options fell into the following categories:

- ***Fuel switching***, i.e., replacing current fuel sources with alternate fuels that result in lower emissions of one or more priority pollutants;
- ***Low cost retrofits and enhanced use of existing control equipment***, i.e., installing low capital cost control devices, or using existing control devices more aggressively (or in alternate ways);
- ***Scheduling changes***, e.g., implementing short-term curtailments or targeted outages;
- ***Dispatch changes***, e.g., shifting load from one boiler to another which has a more effective control device or uses a less polluting fuel;
- ***Combustion optimization*** (or re-optimization), e.g., using sensors, controls or clean-burning combustion modifications to reduce emissions;
- ***Sector-specific opportunities,*** e.g., increasing use of cogeneration units at pulp & paper facilities.

We identified and assessed these options through literature reviews and web research on manufacturing processes and control methods. The main information source for this study, however, has been discussions with sector experts, including industry analysts at ICF and EPA, members of trade associations, independent consultants, corporate environmental managers and plant-level operators.

This study finds there are a number of potential episodic control measures available for each of the three sectors analyzed.

- All three sectors possess some **fuel switching** capabilities and may be able to shift to lower emitting fuels to reduce NOx, SO_2, and/or PM on an intermittent basis for short periods of time. The manner and extent to which short-term fuel switching could be employed,

[1] See *Recommendations to the Clean Air Act Advisory Committee: AQM Subcommittee Phase II Report, June 2007,* http://www.epa.gov/air/caaac/aqm/phase2finalrept2007.pdf.

however, varies from sector to sector. Since facilities typically select their fuels so as to minimize production costs and meet other operational objectives, switching to more expensive fuels on a continuous basis would be untenable for many facilities. However, because fuel switching under an episodic control program would only be invoked on a limited number of days each year, the total incremental costs may be within acceptable levels for many facilities.

- Installation of **low capital cost retrofits**, such as selective non-catalytic reduction (SNCR) and gas reburn systems (for NOx control), and lime injection systems (for SO_2 control) appears to hold promise in the context of an episodic control program. Although the high operation and maintenance (O&M) costs associated with these retrofits (e.g., due to the significant consumption of reagent or natural gas) may make them cost prohibitive for use on a continuous basis at many facilities, they may be suitable for use at some facilities as an episodic control measure.

- Opportunities may exist to modify and thereby **enhance the use of existing pollution control equipment** on a temporary basis to control for additional pollutants (i.e., in addition to the main pollutant(s) these controls are intended for). For example, many industrial boilers and furnaces have venturi scrubbers. These scrubbers are generally installed as PM control devices but may also remove some SO_2 from the exhaust stream of the combustion unit. Some industry analysts and regulatory experts believe there may be an opportunity to enhance the SO_2 removal efficiency of venturi scrubbers in some situations by adding alkali reagent. This may be technically feasible and economically viable where a unit already has such a device and is able to obtain significant incremental SO_2 reductions on a short-term basis with the addition of the reagent.

- Opportunities may also exist to **run existing pollution control devices more aggressively** for short intervals to achieve incremental emission reductions. Some industry analysts thought that in some cases it might be possible to temporarily increase the control efficiency of a variety of NOx, SO_2, and PM control systems on days when high air pollution concentrations occur and where, for cost or other reasons, existing permit conditions do not require these control devices to be utilized at their maximum performance levels.

- While **scheduling changes** involving temporary shutdowns and curtailments that could disrupt core production processes were generally deemed inadvisable, there may be opportunities to curtail certain operations or rearrange production schedules on a short-term basis to move high emitting processes to times when they are less likely to exacerbate air quality problems. For example, because steel mini mill operation is generally batch in nature, some mini mills may be able to reschedule melting operations from daytime to nighttime hours to reduce VOC and NOx emissions, as well as reduce electrical demand, during critical daylight hours when ozone formation is likely to occur. There may also be opportunities to defer certain ancillary activities at cement plants, such as quarrying activities and finishing mill operations, to reduce emissions as well as electrical demand on a short-term basis.

- **Dispatch changes** involving boilers at large pulp and paper mills with excess boiler capacity appear to be a feasible episodic control strategy in some instances.

- Additionally, there may also be other **sector-specific opportunities** for achieving additional emission reductions on an episodic basis, such as increasing the use of cogeneration units in the pulp and paper sector, which require further exploration.

- Episodic control measures related to **combustion reoptimization** techniques appeared less viable for the selected industry sectors. Most facilities in these sectors use sophisticated computer controlled equipment on highly inter-connected and synchronized production processes. Industry experts were reluctant to entertain the idea of altering the already optimized processes, as they might make the processes less efficient and/or more polluting.

While this study has focused primarily on facilities in the pulp and paper, iron and steel, and cement manufacturing sectors, our research and information gathering indicates that a wide variety of episodic control measures may be available for use by sources in other industrial sectors as well.

- Several episodic control measures that are applicable to industrial boilers in the pulp and paper or the iron and steel sectors, may also be broadly applicable to boilers in other industrial sectors. For example, some industrial boilers in other industries may be able to install low capital cost retrofit technologies (such as SNCR or gas reburn for NOx control, or lime injection for SO2 control), to reduce boiler emissions on a short-term basis. Other boilers may be able to temporarily reduce emissions by switching to a lower emitting fuel for limited periods of time. In addition, some boilers that have already been retrofitted with control devices may have the ability to increase the control efficiencies of those devices by modifying their operation or running them more aggressively for short time intervals.

- As with industrial boilers, a number of the episodic control measures applicable to other units and processes in the three selected industries may be applicable to similar units or processes in other industries as well. Examples include fuel switching at furnaces and process heaters, installation of low capital cost retrofits, enhanced use of existing control equipment, and certain scheduling changes. Some sectors may also be able to provide additional, sector-specific opportunities for achieving emission reductions on an episodic basis.

- Several of the episodic control measures examined in relation to the three selected industry sectors involve the rescheduling of electricity-intensive processes to times when they are less likely to exacerbate air quality problems. Other industrial sectors may have similar opportunities to temporarily halt, curtail or defer electricity-intensive processes as part of an episodic control program. These measures could be especially helpful on high electricity demand days when electric utilities may rely on very high emitting generating units in order to meet peak demand for electricity. Reducing peak electricity demand, or shifting that demand from daytime to nighttime hours (when lower-emitting generating capacity is available and the resultant emissions may have less ozone or PM2.5 forming impact), could provide significant air quality benefits. Electric utilities may also have the ability to employ a variety of other episodic control measures to reduce NOx, SO2 and/or PM emissions on days with high air pollution concentrations.

This report is intended to provide a preliminary assessment of the wide array of episodic control measures that may be available to industrial sources. The potential measures identified in this report should be studied further as EPA, states, communities, and other stakeholders consider the potential role that episodic control measures could play in helping to meet ozone and PM2.5 air quality goals. For example:

- To better assess the technical feasibility, emission reduction potential and cost of prospective episodic control measures, it will be necessary to conduct detailed engineering and cost analyses of specific measures. Because of the heterogeneity across facilities within a sector, as well as across sectors, these analyses will need to take into account site-specific and process-level emissions, as well as other source-specific considerations at individual facilities.

- Because the ambient impact of episodic control measures is likely to be spatially differentiated, location-specific air quality modeling will be necessary to determine the actual impact that short-term emission reductions from any particular industrial source or sector would have on local and/or regional air quality problems.

- In order to evaluate the potential utility of episodic control measures it will also be necessary to review state-of-the-art practices pertaining to the prediction of ozone and PM episodes. The effectiveness of episodic control measures would in part depend on the degree of prior notice that can be provided to plant operators, which is in turn a function of the ability of regulatory agencies and/or other institutions to predict air pollution episodes.

Another key step in the further exploration of episodic control measures is to quantify the cost-effectiveness of these measures on a dollar-per-ton of pollutant removed basis. Our discussions with industry analysts indicated this is a major unknown because episodic measures for industrial sources have traditionally been overlooked in the air pollution control literature. It must be emphasized that comparisons to cost-per-ton estimates based on continuous control programs would provide an erroneous picture, as the acceptable cost-effectiveness range for an episodic control program is likely to be substantially higher than the corresponding range for a continuous program. Thus, a better understanding of the range of cost-effectiveness values that could be appropriate given the benefits of an episodic control program needs to be carefully developed.

A number of critical policy issues will also need to be addressed before episodic control measures can be systematically implemented, including whether these measures should be mandated by regulation, negotiated as part of the permitting process, or pursued by individual facilities on a purely voluntary basis.

1. Introduction

I. Background on the Issue

The Air Quality Management (AQM) Subcommittee of EPA's Clean Air Act Advisory Committee (CAAAC) recently recommended expanding the use of episodic control measures to help attain and maintain National Ambient Air Quality Standards (NAAQS) in areas where all reasonable continuous (i.e., year-round) and seasonal control measures have already been required.[2] A number of communities have already developed programs to reduce emissions by individuals and businesses (e.g., from vehicle use, road construction, open burning and other activities), on specific days when high ozone or particulate matter (PM) concentrations are expected. To date, however, few efforts have been made to apply episodic control measures to industrial sources.[3]

Industrial source episodic control measures–-measures that can be implemented intermittently for short periods of time–-could provide an expanded set of control options for states and communities. These options may be particularly useful in areas that are at risk of exceeding the 8-hour ozone NAAQS and/or the 24-hour fine particle (PM2.5) NAAQS only on a limited number of days each year. A variety of measures that could not be implemented on a continuous or seasonal basis could potentially prove suitable and acceptable for episodic use. By reducing peak concentrations on the highest pollution days, episodic control measures can provide considerable health and environmental benefits.[4]

II. Purpose of this Report

The Sector Strategies Division (SSD) within EPA's Office of Policy, Economics, and Innovation (OPEI) undertook this study to help EPA, states, communities, and other stakeholders assess the potential use of episodic control measures by industrial sources. Three industry sectors were selected as case studies for analysis: pulp and paper; iron and steel; and cement.

This study builds on a previous analysis conducted by ICF International in 2006 to identify and qualify a subset of industry sectors as candidates for further episodic control research. Our goal in this current study is to identify, through research and discussions with industry experts nationwide, potential episodic control measures for the three selected sectors that may be technically feasible, practical, and cost-effective, and to assess the implications of these approaches for other industry sectors.

For purposes of this analysis, episodic control measures are defined as measures that could be implemented intermittently, on 24-hours notice, and for a total of up to 10 continuous or non-continuous days per year, to help attain and maintain NAAQS for ozone or PM2.5.

---

[2] See *Recommendations to the Clean Air Act Advisory Committee: AQM Subcommittee Phase II Report, June 2007,* http://www.epa.gov/air/caaac/aqm/phase2finalrept2007.pdf.

[3] Memorandum from Art von Lehe to Barry Elman, EPA Sector Strategies Division, Re: Episodic Control Measures, August 11, 2006

[4] The AQM Subcommittee recognized that legal restrictions currently limit EPA's ability to provide State Implementation Plan (SIP) credit for stationary source episodic control measures. The Subcommittee did, however, recommend expanding the use of such measures as "backup insurance mechanisms" (outside the scope of an approved SIP) for areas working to attain or maintain the short-term ambient air quality standards.

III. Selection of Sectors: Research Scope and Bounds

In 2006, ICF International conducted an analysis for SSD to identify industry sectors that warrant further study with regard to their ability to use episodic control measures to help states and local communities meet their ozone and PM2.5 attainment goals.[5] We used three metrics as screens for that analysis: plant location vis-à-vis nonattainment designations, emissions of relevant criteria air pollutants, and energy consumption.

- ***Plant Location.*** Using a Geographic Information System (GIS) framework, we analyzed sectors based on their geographic distribution and correspondence with current short-term ozone and PM2.5 nonattainment designations. Information on nonattainment status came from the EPA Green Book.[6] The resulting visual representation allowed us to determine sectors that could potentially provide significant episodic emission reductions in nonattainment areas.
- ***Criteria Air Pollutant (CAP) Emissions.*** We analyzed air emissions profiles for all 28 industry sectors included in the 2001 Aerometric Information Retrieval System (AIRS) and estimated their relative contributions to total CAP emissions (i.e., VOC, NOx, SO_2, and PM2.5) that contribute to ozone and PM2.5 air quality problems.
- ***Energy Consumption.*** Building on SSD's on-going analysis of strategies to promote environmentally-preferable energy outcomes in selected manufacturing sectors,[7] we analyzed the energy intensities and fuel mix for those selected sectors to determine whether there may be short-term changes in fuel use and combustion equipment that may offer significant potential for episodic emission reductions.

Based on these screening assessments, we identified a number of sectors as good candidates for further study of potential episodic control measures, including the pulp and paper, iron and steel, and cement sectors. Section 2 of this report provides updated location maps for these three sectors, while Exhibit 1, below, provides updated emissions data.[8]

[5] "*Selecting Sectors for Analysis of Potential Episodic Control Measures*", ICF technical memorandum to Barry Elman, EPA Sector Strategies Division. September 29, 2006.
[6] See http://www.epa.gov/oar/oaqps/greenbk/index.html.
[7] See March 2007 final report, *Energy Trends in Selected Manufacturing Sectors: Opportunities and Challenges for Environmentally Preferable Energy Outcomes*, prepared by ICF for SSD, http://www.epa.gov/ispd/energy/index.html.
[8] While the three sectors selected for case studies all have manufacturing facilities located in ozone and/or PM2.5 nonattainment areas, and they all emit significant quantities of criteria pollutants and operate energy intensive processes, further analysis (including assessment of site-specific emissions, stack parameters, air chemistry, atmospheric transport and other factors) would be necessary in order to fully characterize the air quality impacts of any individual facility or industry sector.

Exhibit 1: Point Source Emissions from Selected Manufacturing Sectors as a Percentage of All Manufacturing Sectors

Sector	VOC	NO_x	SO_2	PM2.5
Pulp & Paper*	8%	14%	15%	12%
Iron & Steel**	1%	4%	3%	7%
Cement***	1%	15%	8%	6%
All Manufacturing Sectors*****	100%	100%	100%	100%

* Pulp and Paper is defined as NAICS codes 32211, 322121 and 322122, or SIC codes 261 and 262
** Iron & Steel is defined based on a list of facilities developed by EPA's Sector Strategies Division
*** Cement is defined based on a list of facilities developed by EPA's Sector Strategies Division
**** All Manufacturing Sectors is defined as NAICS codes 31-33, or SIC codes 20-39

Source: *U.S. EPA's Final v2 2002 National Emission Inventory (NEI) for Criteria Air Pollutants from Point Sources*

IV. Methodology, Data Sources, and Caveats

Building upon our 2006 analysis, we researched specific technological options for achieving intermittent, short-term emission reductions across the target sectors. These options fell into the following categories:

- ***Fuel switching***, i.e., replacing current fuel sources with alternate fuels that result in lower emissions of one or more priority pollutants;
- ***Low cost retrofits and enhanced use of existing control equipment***, i.e., installing low capital cost control devices, or using existing control devices more aggressively (or in alternate ways);
- ***Scheduling changes***, e.g., implementing short-term curtailments or targeted outages;
- ***Dispatch changes***, e.g., shifting load from one boiler to another which has a more effective control device or uses a less polluting fuel;
- ***Combustion optimization*** (or re-optimization), e.g., using sensors, controls or clean-burning combustion modifications to reduce emissions;
- ***Sector-specific opportunities,*** e.g., increasing use of cogeneration units at pulp & paper facilities.

We identified and assessed these options through literature reviews and web research on manufacturing processes and control methods. The main information source for this study, however, has been discussions with sector experts, including industry analysts at ICF and EPA, members of trade associations, independent consultants, corporate environmental managers and plant-level operators. Within the constraints of time and resources, we conducted a limited set of interviews, seeking information and expert opinions to vet the technical feasibility, practicality and cost-effectiveness of these potential options. As a result, some information is anecdotal, and there are technical points on which knowledgeable opinions vary.

Clearly, consideration of episodic control measures for industrial sources is in its formative stage. This report is intended to provide a preliminary basis for assessing the wide array of options that may be possible. Based on this analysis, however, we cannot say definitely which measures will or will not be viable, or what benefits they will provide. The potential measures identified in this report should be studied further as EPA, states, communities and other stakeholders consider options for achieving ozone and PM2.5 attainment goals.

V. Report Outline

The major sections of this report are organized as follows:

- ***Section 2, Sector Options and Analyses***, explores potential episodic control measures for each of the three sectors selected as case studies for this analysis, and considers the applicability of these measures to other industrial sources.
    - The first three subsections present the results of our research on the three selected sectors: 2.I, pulp and paper; 2.II, iron & steel; and 2.III, cement. We begin each sector's discussion by presenting an overview of its manufacturing processes and related emissions, as well as by providing maps that show the location of the sector's facilities in relation to nonattainment areas for ozone and PM2.5. We then provide our detailed analysis of potential episodic control measures, followed by summaries of our main findings in text boxes.
    - Section 2.IV highlights the implications of our analysis for other sectors, focusing on potential measures for industrial boilers, as well as for electric utilities and other industrial sources.
- ***Section 3, Summary of Findings & Next Steps***, summarizes our findings across the three selected sectors, as well as the implications for other sectors, and presents consolidated next steps.
- ***The Appendix*** describes the effects that the 2001 and 2005 rolling blackouts in California had on the performance of several industry sectors, to inform discussion on how these or other sectors might react to unscheduled outages in the context of an episodic control program.

2. Sector Options and Analyses

I. Pulp and Paper

a. Overview of the Pulp & Paper Manufacturing Process and its Emissions

Pulp and paper manufacturing can be broken down into five significant steps: [9]

- ***Wood preparation*** involves removing the bark from logs and then breaking down the debarked logs into wood chips of uniform size. The uniformity in the chip size maximizes the quality and efficiency of the subsequent pulping process.

- ***Pulping*** then converts the fibrous wood material into a slurry of fibers. Pulping involves cooking the wood fibers, washing, and screening to remove unwanted materials. Three different types of pulping technologies are used, depending on the desired properties of the final product and the corresponding amount of lignin that needs to be removed from the paper.[10] Chemical pulping removes the most lignin, semichemical pulping removes some lignin, while mechanical pulping does not remove any lignin.

- ***Chemical recovery,*** which is part of the pulping process, enables the recovery and reuse of chemicals used in the chemical and semichemical pulping process. Steam and electricity generated during the recovery process also help offset the large energy requirements of pulp and papermaking.

- ***Bleaching*** is a chemical process used to whiten or brighten the pulp before it is used in papermaking. Different bleaching techniques are used depending on the specific pulping process and the residual lignin left in the pulp.

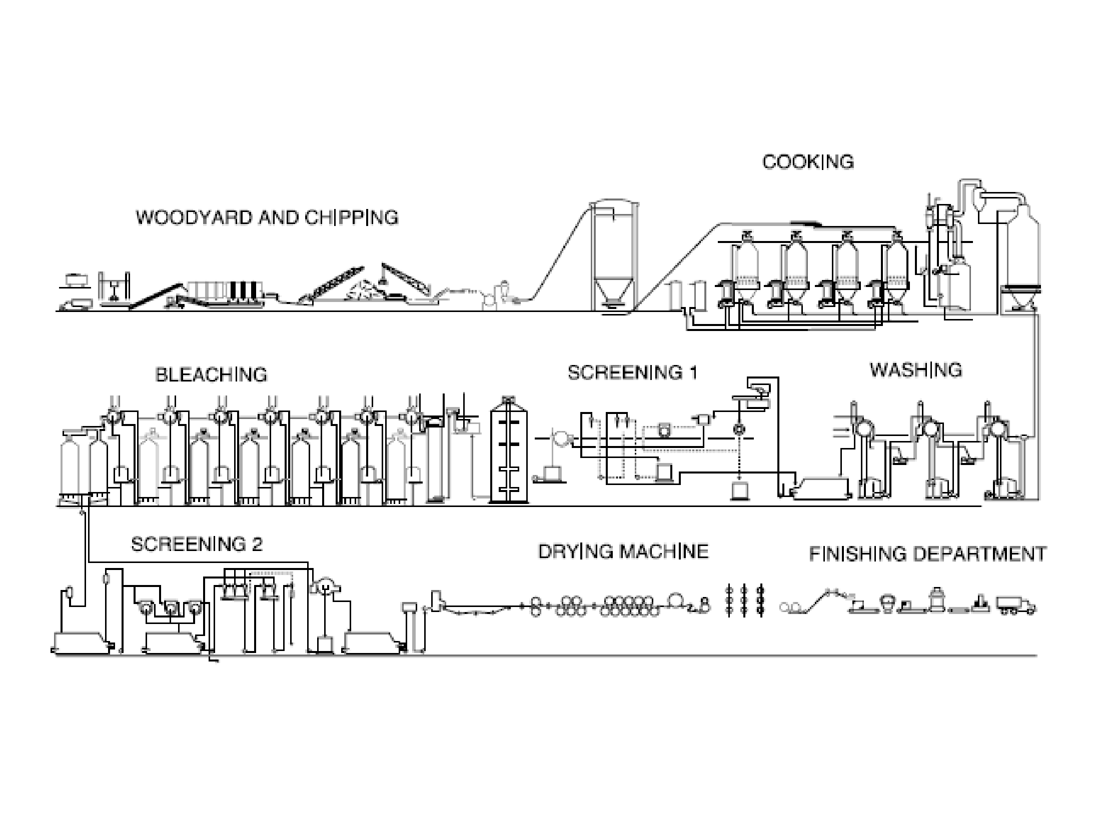
- **Papermaking** is the final stage consisting of four steps:
  - Preparing a homogeneous pulp slurry (stock);
  - Dewatering the slurry;
  - Pressing and drying to manufacture the paper; and
  - Finishing the manufactured paper. Depending on the final product desired, finishing can involve one or more of the following processes – rewinding the paper onto a reel, trimming, coating, printing, saturation, and box-making.

Exhibit 2 presents a simple flow diagram of the basic pulp and paper manufacturing process, applicable for all three types of pulping processes – chemical, semichemical, and mechanical pulping.

[9] The following overview of the pulp and paper manufacturing process and emissions is taken from the DOE/ITP report on the pulp and paper industry; (*Energy and Environmental Profile of the U.S. Pulp and Paper Industry*, US DOE, Office of Energy Efficiency and Renewable Energy, Industrial Technologies Program, December 2005). This overview describes the process at an integrated pulp and paper mill. The industry also has a large number of non-integrated mills that purchase pulp to make paper and others that obtain and process recycled fibers for papermaking.

[10] Wood lignin holds the wood fiber together and adds strength and stiffness to trees, but also results in weaker paper that yellows with age.

Exhibit 2: Basic Pulp & Papermaking Process



Source: *Smook, 1992 (from EPA Sector's Notebook, November, 2002)*

Exhibit 3 below shows the relative shares of the different fuel types used in the pulp and paper industry in 2002. The "Other" fuel category, which primarily includes biomass, is the dominant fuel at about 54 percent of the total. Biomass fuel includes spent liquor or black liquor[11] (approximately 70 percent of the "Other" category) and wood residues and byproducts (approximately 27 percent of the remainder). The next biggest fuel source is natural gas at 21 percent, followed by coal and electricity at 10 percent and 9 percent, respectively.

Exhibit 3: Primary Fuel Inputs as Fraction of Total Energy Supply for the Pulp & Paper Industry in 2002 (fuel use only)

Coal	Other	Net Electricity	Natural Gas	Fuel Oil
10%	54%	9%	21%	5%

Source: *Energy Trends in Selected Manufacturing Sectors*, EPA Sector Strategies Division, March 2007, based on *DOE/EIA Manufacturing Energy Consumption Survey, 2002 Data Tables*. Totals may not add to 100 percent due to rounding.

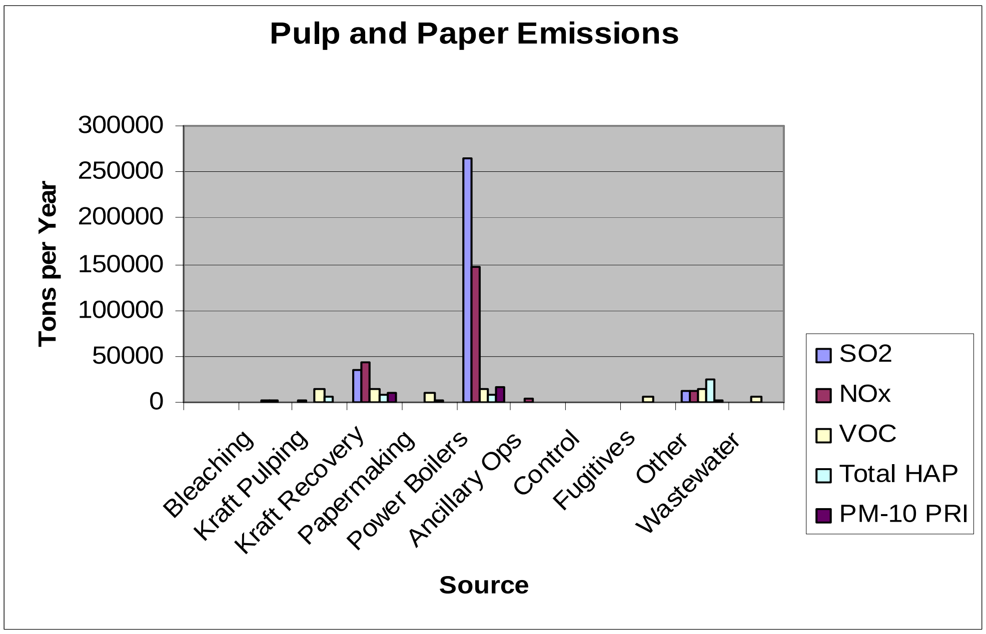
Net electricity provides a rough approximation for purchased power and includes purchased electricity, transfers in, and generation from noncombustible renewables, and excludes electricity transferred out or sold.

[11] Black liquor is a byproduct generated in the chemical pulping process. Boilers fired with black liquor have an efficiency of about 70 percent, compared to 80-85 percent for coal- or natural gas-fired boilers of same size. (Source: *Characterization of the U.S. Industrial/Commercial Boiler Population*, Oak Ridge National Laboratory, May 2005.)

Air Emissions

The biggest emission sources in a pulp and paper mill are the power boilers used to generate steam and electricity for sustaining the pulp and papermaking process. These power boilers consume all of the coal used by this sector and produce significant amounts of SO_2 (about 83 percent of the total for this industry) and NOx (about 77 percent of the total), and some VOC. The second biggest emission source is the kraft recovery furnace. While recovery furnaces generate significantly lower SO_2 and NOx emissions than the power boilers, their VOC emissions are similar to those from the power boilers. Power boiler PM emissions are generally well controlled through venturi scrubbers, baghouses or ESPs, while ESPs are by far the dominant PM control device on kraft recovery furnaces. Exhibit 4 presents process-specific emissions from the pulp and paper industry.

Exhibit 4: Process Specific Emissions in 2002



Source: *SO_2 and NOx Emissions from U.S. Pulp and Paper Mills, 1980-2005.* National Council for Air and Stream Improvement (NCASI) analysis (based on Draft 2002 NEI data).

b. Location

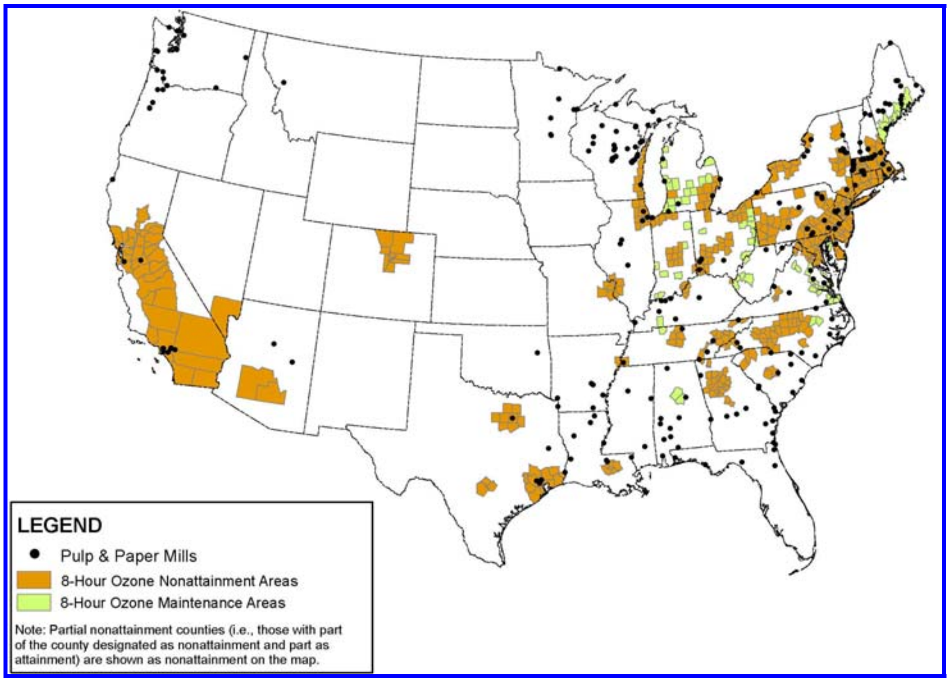
There were 425 pulp and paper mills, including 148 integrated mills, operating in the U.S. in 2005.[12] The location of mills and facilities appears to be largely driven by the location of wood sources, rather than energy sources. For example, pulp mills that use virgin woods tend to be in regions where trees are harvested, including the Southeast, Northwest, Northeast, and North Central regions. Pulp mills that rely on recycled fiber are located near sources of waste paper. Nonintegrated paper mills often are located near pulping operations, since this is their primary input.[13] Exhibit 5 below presents the location of pulp and paper mills in relation to nonattainment and maintenance areas for the current 8-hour ozone NAAQS, as of October

[12] *Pulp and Paper Mill Emissions of SO2, NOx, and Particulate Matter in 2005, Special Report No. 06-07,* National Council for Air and Stream Improvement (NCASI), December 2006.

[13] *Analysis of Energy Usage in Selected Industrial and Commercial Sectors*, US EPA, Sector Strategies Division, May 24, 2006.

2007.[14] [15] Exhibit 6 presents the location of pulp and paper mills in relation to counties violating the current 24-hour PM2.5 NAAQS, based on 2004-06 monitoring data.[16] While these exhibits indicate that a number of pulp and paper mills are located in or near areas that currently violate the short-term standards for ozone or PM2.5, it should be noted that many of these areas are projected to attain the standards in the near term while other areas are at risk of violating the standards in the future. It should also be emphasized that source-specific factors, including process-level emissions, stack parameters, topography, meteorology, and air chemistry, would need to be taken into account when assessing the air quality impact of any individual facility or sector on local or regional air quality problems.

Exhibit 5: Location of Pulp and Paper Mills in Relation to 8-Hour Ozone Nonattainment and Maintenance Areas



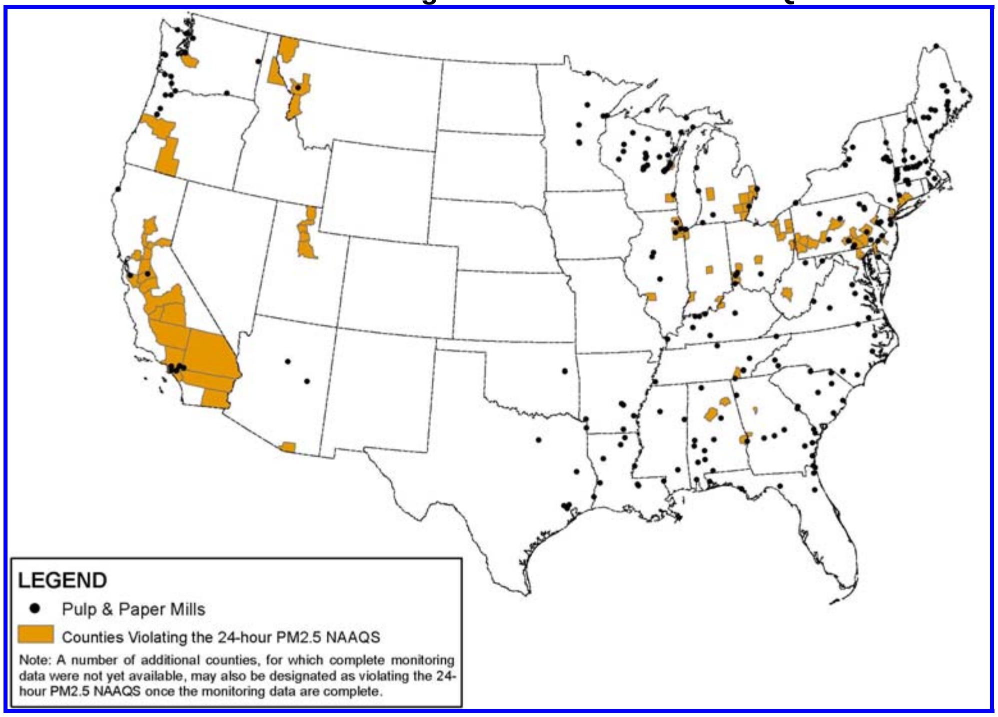
Sources: *Pulp and paper mill locations obtained for facilities listed with SIC codes 261 and 262, or NAICS codes 32211, 322121 and 322122, in 2002 (v2) National Emissions Inventory (NEI) CAP Point Source Dataset. Nonattainment and maintenance areas for the current 8-hour ozone NAAQS obtained from EPA's Green Book: Nonattainment Status for Each County by Year, October 2007.*

[14] The locations of pulp and paper mills were obtained for facilities listed with SIC codes 261 and 262, or NAICS codes 32211, 322121 and 322122, in 2002 (v2) National Emissions Inventory (NEI) CAP Point Source Dataset. Data on nonattainment and maintenance areas for the current 8-hour ozone NAAQS were obtained from EPA's *Green Book: Nonattainment Status for Each County by Year*, October 2007, available at http://www.epa.gov/oar/oaqps/greenbk/map8hrnm.html and http://www.epa.gov/oar/oaqps/greenbk/anay.html.

[15] EPA proposed tightening the 8-hour ozone NAAQS on July 11, 2007. See: http://www.epa.gov/air/ozonepollution/pdfs/20070711_proposal_fr.pdf.

[16] The locations of pulp and paper mills were obtained for facilities listed with SIC codes 261 and 262, or NAICS codes 32211, 322121 and 322122, in 2002 (v2) National Emissions Inventory (NEI) CAP Point Source Dataset. Data on counties violating the current 24-hour PM2.5 NAAQS were obtained from EPA's Air Quality System (AQS) as of July 11, 2007, available at http://www.epa.gov/airtrends/values.html.

Exhibit 6: Location of Pulp and Paper Mills in Relation to Counties Violating the 24-Hour PM2.5 NAAQS



Sources: *Pulp and paper mill locations obtained for facilities listed with SIC codes 261 and 262, or NAICS codes 32211, 322121 and 322122, in 2002 (v2) National Emissions Inventory (NEI) CAP Point Source Dataset. Counties violating the current 24-hour PM2.5 NAAQS (based on 2004-06 monitoring data) obtained from EPA's Air Quality System (AQS) as of July 11, 2007.*

c. Potential Episodic Control Measures

We focused our analysis on five categories of potential episodic control measures for the pulp and paper sector:

- Fuel switching;
- Low cost retrofits and enhanced use of existing control equipment;
- Dispatch changes;
- Scheduling changes; and
- Cogeneration.

i. Fuel switching

Several short-term fuel switching options appear to have potential as episodic control measures for the pulp and paper industry:

The pulp and paper industry uses a large number of power boilers and coal is a major fuel source for many of these boilers. Coal accounts for a disproportionate share of the SO_2 and NOx emissions from power boilers, and there appears to be some potential for switching from coal to other lower emitting fuels, such as biomass or natural gas, for short time periods in many power boilers. [17]

Most power boilers in this industry are "combination boilers" capable of burning multiple fuel types. Combination boilers can shift between fuel types on short notice and are generally designed to run up to 100 percent on any of the fuels they are designed to handle. According to industry analysts, many combination boilers routinely burn coal and biomass, with the percentage breakdown between the two fuel sources varying over time and across facilities. Typically, facilities that burn biomass have at least a one week onsite supply of biomass fuel. Thus, facilities burning both coal and biomass in a combination boiler may have the flexibility to increase their use of biomass, or even to use biomass as the only fuel source, for short periods, if needed. Industry analysts felt that if biomass was used to displace coal there should be significant SO_2 and NOx emission reduction benefits. Further analysis is, however, needed to confirm that facilities with combination boilers have the ability to shift on short (i.e., 24-hours) notice to a higher share of biomass in their fuel mix (i.e., up to 100 percent biomass) for short periods of time, since current permit limitations and/or operational constraints could restrict such changes. Further analysis is also needed to determine the magnitude of the SO_2 and NOx emission reductions that short-term fuel switching from coal to biomass could provide, as well as the impact on other pollutants, and to more fully assess the cost and operational impacts on individual facilities.

Another potential short-term fuel switching option for power boilers is switching from coal to natural gas. Switching to natural gas on a short-term basis appears to be technically viable for many facilities since most boilers have natural gas firing capability. The key issue with regard to this fuel switching option appears to be cost. Facilities may have to make limited capital expenditures to prepare for using natural gas, and would have to establish operational procedures, train staff and maintain equipment on an ongoing basis in order to ensure "operational readiness" to switch over to natural gas on short notice. Moreover, facilities would need to secure a reliable natural gas supply, and this would likely entail a significant price premium (over the already high cost of natural gas) in order to ensure sufficient access to natural gas on short notice. Nevertheless, some industry analysts thought it was conceivable that the cost of shifting to natural gas on a limited number of days with high air pollution concentrations could be less than the cost of installing further add-on controls. This would need to be confirmed through further analysis, as would the magnitude of the SO_2 and NOx reductions, and the operational impacts on individual facilities, that would result from implementing this strategy.

In addition, industry analysts also noted that some pulp and paper mills in the Midwest use high sulfur coal and may be good candidates for switching to lower sulfur coal on days with high air pollution concentrations, such as coal from the Powder River Basin (PRB). Although such a switch might entail additional fuel and/or transportation costs, the proximity of these mills to PRB in Wyoming and lower rail tariffs resulting from railway deregulation may make this switch a viable and cost-effective episodic control strategy for some mills.[18] Pulp and paper mills that employ this strategy would need to stockpile and manage a secondary coal supply, which would

[17] The combustion of coal and biomass both result in higher PM emissions than the combustion of natural gas and together they account for most of the PM emitted from power boilers in the pulp and paper sector.

[18] Industry analysts pointed out there may also be costs associated with equipment modifications needed to burn subbituminous versus bituminous coal and there may be technical feasibility constraints to the use of PRB coal in cyclone boilers.

further increase operating costs and could potentially raise other logistical or operational issues. Moreover, unlike electric utilities, pulp and paper facilities are not primary purchasers of coal and may be restricted by existing long-term coal contracts.[19] Therefore, they may be constrained in their ability to obtain (or replenish) low sulfur coal supplies. Nevertheless, switching from high- to low-sulfur coal on short (i.e., 24 hours) notice warrants further exploration as a potentially viable and cost-effective episodic control strategy for some Midwestern mills that currently burn high sulfur coal.

Another fuel switching option that might work for smaller mills is switching from residual oil to natural gas. Most small mills have package boilers designed to burn fuel oil and/or natural gas. According to industry analysts, many of these boilers currently burn residual oil but can switch to natural gas on short notice. This switch can provide significant SO_2 and NOx emission reduction benefits. Switching from residual oil to natural gas may be a particularly attractive option for small mills located in or near urbanized areas experiencing air quality problems. There are several concerns, however, with burning more natural gas at small facilities; these concerns relate to accessibility, availability, and cost.

- Some small mills may not have access to a natural gas pipeline and would therefore be unable to switch over to this fuel on days with high air pollution concentrations.
- Because natural gas is in high demand for heating purposes during the winter, as well as on high electrical demand days during the summer, particularly in the Northeast where a number of small mills are located, issues related to availability and price would need to be assessed to determine the true viability of this option for small mills.[20]

For small mills with package boilers that burn residual oil, an alternative strategy could be to switch to LPG or propane instead of natural gas. Our discussions with industry analysts indicated that some mills might be able to store a limited supply of LPG onsite for use on days when high air pollution concentrations occur. Alternatively, with a 24-hour lead time, mills might be able to arrange to have LPG tanker(s) brought onsite to supply enough LPG to replace residual oil for a short period of time (e.g., 8-12 hours). Our discussions indicated that this might be a viable and cost-effective strategy for a number of small mills given the nature of their operations, even though modest capital expenditures may be required (e.g., to install new burners) before a boiler would be equipped to burn LPG.[21] Further research is needed on the costs and operational impacts of implementing this strategy. In addition, permitting restrictions may need to be addressed in order to allow mills to store and/or use LPG as an episodic control measure.

[19] Primary purchasers of coal are those facilities/industries that are the main buyers of coal, and may therefore have some influence on the type of coal being shipped as well as delivery schedules.
[20] Mills might need to pay a price premium to secure a guaranteed, as-needed supply.
[21] Switching from residual oil to distillate oil or diesel fuel may also be feasible with the installation of new burners and a separate fuel storage tank.

Summary: Fuel Switching

There appear to be several potential fuel switching options for achieving significant short-term SO_2 and NOx emission reductions from power boilers as part of an episodic control strategy for the pulp and paper industry.

For bigger mills, the most promising short-term fuel switching opportunities would occur at combination boilers. Many of these boilers use large quantities of coal and may have the capability to temporarily use *more* biomass or natural gas in its place to achieve significant emission reductions. There might also be opportunities to switch from high- to low-sulfur coal for short intervals at some Midwestern mills.

For small mills, short-term shifts from residual oil to natural gas or LPG/propane in package boilers seem to hold promise. This strategy might be particularly useful where small mills are located in or near urbanized areas with air quality problems.

ii. Low-cost retrofits and enhanced use of existing control equipment

Another set of episodic control measures we considered entails the use of add-on control equipment. Although most pollution control retrofits require significant capital expenditures for installation, there are some that have relatively low installation costs but higher operation and maintenance (O&M) costs. Such low-capital, high O&M retrofits may be cost-effective to operate for short time periods during an episodic air pollution event. Similarly, where control technologies are already deployed, it may be possible to run them more aggressively for short intervals, or in other ways that would not be feasible or cost-effective on a continuous basis.

We identified four control technologies that seemed to have potential as episodic control measures for the pulp and paper industry:

- Selective non-catalytic reduction (SNCR)
- Gas reburn
- Venturi scrubbers
- Lime injection

SNCR for NOx Control

A number of industry analysts suggested that the use of SNCR systems may be a viable episodic control measure for reducing NOx emissions from facilities in the pulp and paper industry, particularly for base-loaded boilers (i.e., boilers that run continuously, or close to it). SNCR systems can be used with base-loaded boilers firing any fuel (coal, wood, gas, etc.). Some analysts have stated, however, that if the boiler load fluctuates significantly, there may be technical problems with installing SNCR systems on such boilers. According to these analysts, SNCR is not a proven technology on industrial boilers with fluctuating loads. However, one SNCR vendor we spoke with has stated that SNCR has been demonstrated on many industrial boilers with fluctuating load and that the cycling boilers in the pulp and paper industry do not present special technological challenges.[22] Thus, the use of SNCR systems as an episodic control measure holds promise for base-loaded boilers in the pulp and paper industry. However,

[22] This vendor said that it would guarantee the performance of SNCR on cycling boilers at pulp and paper mills, although site-specific modeling would be required before a guarantee could be issued with regard to any specific installation.

the extent to which these systems can be used as an episodic control measure for cycling boilers would need to be further analyzed to reconcile the differing viewpoints.[23]

In those instances where the use of SNCR systems is technically feasible, the limiting factor is generally the cost of implementing these systems. According to industry analysts and technology vendors, the cost of purchasing and installing an SNCR system may be on the order of $1 million or more for a large industrial boiler. However, for large boilers, most of the total annualized costs associated with an SNCR system is for the reagent used (urea or aqueous ammonia). Therefore, the cost burden associated with installing and operating an SNCR system could be reduced significantly under an episodic control program. For example, in the case of a large boiler it might be possible to reduce the total cost burden of an SNCR system by 50 percent or more if the system were installed and run at an intermediate (e.g., 30 percent) control level on a continuous basis, and then ramped up to full capacity (e.g., 50 percent control efficiency) on days with high air pollution concentrations. The cost burden could be further reduced if the SNCR system were kept on standby and used only on days with high air pollution concentrations.

A major concern expressed by industry analysts was that once an SNCR system is installed and available for use as part of an episodic control program, regulators and/or community activists may demand that it be run at full capacity on a continuous basis. Further analysis of the technical feasibility, emission reduction potential and cost of this option with respect to different boiler types, fuels and operating conditions is required.

Gas Reburn for NOx Control
Another NOx control technology that might be viable as an episodic control measure for this sector is natural gas reburn. According to industry analysts, stoker wood-fired boilers in the pulp and paper industry may be ideal candidates for additional NOx control using intermittent gas reburn. Since most facilities may have access to natural gas (for use as a boiler starter fuel, for example), the incremental costs of using gas reburn may be limited to the costs of installing additional burners and using natural gas. Because the strategy would only be used intermittently and for short periods, however, mills would require relatively limited quantities of natural gas. Thus, the total incremental costs may be within acceptable levels for many large mills.[24]

Venturi scrubbers for SO_2 Control
About 25 percent of the combination boilers in the pulp and paper industry that burn both coal and wood have venturi scrubbers. These scrubbers are installed for PM control but may also have the capability to further reduce SO_2 emissions by as much as 80 percent when alkali reagent is used. Some mills already use alkali reagent in their venturi scrubbers to reduce SO_2 emissions, however, the vast majority do not. The main reason why venturi scrubbers have not been widely utilized as an SO_2 abatement strategy is because they are generally not considered to be efficient or cost-effective for that purpose – according to one industry analyst they may waste about half the reagent used.[25] The use of alkali reagent to achieve additional SO_2

[23] Another issue needing further evaluation according to some industry analysts is the potential for ammonium sulfate formation in the case of boilers with high sulfur fuels.
[24] Although natural gas reburn has fallen out of favor as a continuous control strategy in the current scenario of high gas prices, its use as an episodic strategy may still be a worthwhile avenue of research.
[25] Facilities that need to scrub SO_2 on a continuous basis would generally install packed tower scrubbers or other SO_2 control technologies that are more efficient in their use of alkali reagent, and are capable of achieving SO_2 reductions of 90 percent or more.

emission reductions may, however, be technically feasible and cost-effective as an episodic control measure for those facilities that have already installed venturi scrubbers, insofar as they could achieve a significant incremental reduction in SO_2 emissions on a short-term basis for a modest cost with the addition of alkali reagent.[26]

Lime injection for SO_2 Control

Mills that use baghouses or electrostatic precipitators (ESP) for PM control may have the option to inject dry lime powder into the duct that carries exhaust gases from a power boiler to the PM control device, to get additional SO_2 removal. The costs for implementing this control strategy could include the cost of installing storage, transfer and injection systems for the lime, and the cost of the lime reagent itself. For kraft mills with existing baghouses or ESPs on their boilers, this strategy may be particularly attractive and cost-effective because lime is already available at the mill (although the particle size distribution that is needed for lime injection may not be easily available). Moreover, in the case of baghouses, caking of the lime on the baghouse walls would provide enhanced control efficiency for SO_2, with over 70 percent control efficiencies possible according to one expert. For mills that use ESP for PM control, the absence of caking on the walls would imply that their control efficiencies would be lower, thereby increasing the cost-per-ton of SO_2 removed. Even with ESPs, however, lime injection may still be able to achieve significant short-term SO_2 reductions at modest cost.

Summary: Low Cost Retrofits and Enhanced Use of Existing Control Equipment

Most industry analysts agree that it is technically feasible to install SNCR systems on base-loaded boilers in the pulp and paper industry. Because of the relatively low capital costs and the limited use of reagent, installing and using SNCR systems as part of an episodic NOx control program may be a cost-effective strategy for these boilers. There is some dispute, however, as to the technical feasibility of installing SNCR systems on pulp and paper industry boilers with vacillating load. Further analysis of the technical feasibility and cost of this option with respect to different types of boilers and operating conditions is required.

Another NOx control technology that may warrant further consideration as an episodic control measure is natural gas reburn. Although the high price of natural gas makes this technology less appealing for use on a continuous basis, it may be cost-effective for use as an intermittent, short-term control strategy.

The addition of alkali reagent to venturi scrubbers to achieve further SO_2 reductions appears to be a promising episodic control measure for mills that have already installed these scrubbers for PM control purposes. These mills would need to incur the additional cost (O&M) of using reagent only on a limited number of days when high air pollution concentrations occur (as well as the cost of installing an alkali addition system for those mills that do not presently have such a system). Its effectiveness, however, would vary depending on the fuel mix used in the boilers and other site-specific factors.

For those mills that use baghouses or ESPs for PM control, lime injection may be a viable and cost-effective episodic SO_2 control measure.

[26] The SO_2 reduction resulting from the addition of alkali reagent would also depend on the coal/wood fuel mix in the boilers. If the boiler burns mostly coal and very little wood (say 90-10 ratio), then adding reagent can provide up to 80 percent SO_2 reduction.

iii. Dispatch changes

According to industry analysts, a typical large, integrated mill may have several power boilers, e.g., two large combination boilers and two smaller package boilers designed to burn fuel oil and/or natural gas. One or more of these boilers would likely be base-loaded and the others cycled as needed. In some cases, an integrated mill may also have an idle package boiler that could be brought online to burn natural gas with as little as one hour of lead time. Thus, at any given moment, a mill may have some excess boiler capacity, and this capacity could occur at a boiler that burns cleaner fuel or has a more efficient control device than a boiler that is currently being utilized. Most boilers within a facility are inter-connected so that load can be shifted from one to another. Therefore, from a theoretical standpoint, mills may have some ability to dispatch different boilers at different times to attain episodic emission reduction goals. Further research is needed, however, to determine the magnitude of the emission reductions that could result from short-term dispatch changes, and to more fully assess the cost and operational impacts on individual facilities.

Another possible dispatching strategy for pulp and paper mills involves generating more steam at recovery furnaces, on a short-term basis, to reduce the load on power boilers. Most of the steam that is required at an integrated mill is provided by burning black liquor in the recovery furnace. Although the recovery furnace is typically operated at a high utilization rate, there may be some ability to further increase its capacity utilization on a temporary basis. For example, a recovery furnace that is operating at 85 percent of its maximum capacity could be ramped up to 90 or 95 percent for a short interval in order to reduce the demand for steam from boilers, thereby reducing the need to run the boilers to generate steam. Based on our discussions, it appears that recovery furnaces can be readily cycled up or down, and most mills have a sufficient stockpile of black liquor to allow for a one or two day increase in the furnace's utilization rate. [27] Because black liquor has lower fuel heat content than coal, more black liquor would be needed to generate the same amount of energy. Nevertheless, due to the lower SO_2 and NOx emissions generally resulting from black liquor combustion compared with most fossil fuels, it may be possible to achieve a net reduction in SO_2 and NOx emissions. Further research is needed to determine the magnitude of the emission reductions that could be achieved by increasing steam generation at the recovery furnace on a short-term basis, and to more fully assess the cost and operational impacts on individual facilities.

Summary: Dispatch Changes

Changing boiler dispatch as an episodic control strategy may work for some integrated pulp and paper mills to the extent that they have excess capacity at low emitting boilers on days with high air pollution concentrations. In addition, integrated mills may be able to temporarily increase steam production at their recovery furnace in order to reduce their reliance on higher emitting power boilers to generate steam.

[27] In addition, many recovery furnaces have load-carrying oil or gas burners that could be used to produce additional steam. Use of auxiliary oil would not increase SO_2 emissions due to capture of the oil sulfur by sodium fumes inside the furnace. Additional NO_x from auxiliary gas or oil burning in the furnace would still be less than the NO_x produced from coal combustion on a lb/lb steam produced basis. However, there could be air permitting issues associated with increased auxiliary fuel burning.

iv. Scheduling changes

Short-term scheduling changes appear to be the least viable episodic strategy for pulp and paper mills, as they almost always strive to operate at constant capacity in order to maintain maximum production efficiency. Industry analysts indicated that short-term changes to mill operations would likely reduce production efficiency and therefore be cost prohibitive. Moreover, short-term disruptions in mill operations could increase emissions intensity (emissions per unit of production), and potentially increase net emissions from a facility.

Summary: Scheduling Changes

Industry analysts agreed that scheduling changes would generally not be effective as an episodic strategy for pulp and paper mills.

v. Cogeneration

The pulp and paper industry is one of the largest cogeneration applications among all industry sectors. Cogeneration is considered an environmentally preferable generating technology, because the simultaneous production of thermal and electric energy from the same fuel source is more efficient than generating just electricity. Onsite electricity generation also eliminates energy losses associated with transmission and distribution of power over the electric grid. According to industry analysts, a significant portion of the pulp and paper industry's cogeneration is considered emission neutral, because it uses primarily the steam generated from the pulping process. More than 65 percent of the industry's electricity needs are met through cogeneration processes.[28]

Most analysts we spoke with agreed that the pulp and paper industry may have the ability to further increase its electricity generation through its cogeneration systems on a short-term basis (i.e., provide a "surge capacity"), but this would need to be studied further. Moreover, any strategy that involves increasing electricity generation from the pulp and paper industry for short time intervals would need to evaluate the tradeoffs associated with displacing electricity generated by power plants. While it is possible that increased electricity generation at pulp and paper mills could displace generation from high emitting electrical utility units on high electricity demand days, further research is needed to determine the extent to which net emission reductions would result from this strategy, and to more fully assess the cost and operational impacts on individual mills.

Summary: Cogeneration

Pulp and paper mills already lead all industry sectors in cogeneration, but they may still have some excess capacity to increase their electricity generation on days when high air pollution concentrations occur. However, any strategy to increase the pulp and paper industry's electricity generation would need to consider the tradeoffs associated with displacing electricity generated by power plants. Moreover, concerns exist in how increased cogeneration would impact the pulp and paper industry's relationship with power plants and electricity rates. More analysis is needed to determine whether this can be a viable episodic strategy.

[28] *Analysis of Energy Usage in Selected Industrial and Commercial Sectors*, US EPA, Sector Strategies Division, May 24, 2006.

d. Opportunity Assessment of Potential Episodic Control Options

Exhibit 7 summarizes the potential viability of the five primary options for further reducing emissions on days with high air pollution concentrations.

Exhibit 7: Opportunity Assessment – Pulp & Paper

Option	Viability as Potential Episodic Control Measure
Fuel switching	**Promising** – Several short-term fuel switching options appear to have potential as episodic control measures (for SO_2 and NOx reductions)
Low cost retrofits and enhanced use of existing control equipment	**Promising** – SNCR for base-load boilers (for NOx reductions); venturi scrubbers and lime injection (for SO_2 reductions) **Needs further study** – Gas reburn (for NOx reductions)
Dispatch changes	**Possible** – For large mills with multiple power boilers and/or a recovery boiler operating below maximum capacity on days when high air pollution concentrations occur (for SO_2 and NOx reductions)
Scheduling changes	**Unlikely**
Increased cogeneration	**Needs further study**

II. Iron & Steel

a. Overview of the Iron & Steel Manufacturing Process and its Emissions

As detailed in Exhibit 8, the iron and steel manufacturing process can be broken down into the following four major steps: cokemaking, ironmaking, steelmaking, and forming and finishing.[29]

- **Cokemaking** uses coal to generate coke, coke oven gas, and by-product chemicals from compounds released from the coal. Coke is produced by heating metallurgical coal (also called "coking coal") in such a manner as to drive off the volatile substances commonly present in coal, producing a carbon-rich coke.

- In the traditional method of **ironmaking**, iron-bearing materials are reduced to molten metallic iron (called "pig iron") in a blast furnace, using carbon present in coke as a reducing agent. The iron-bearing materials are pellets or sinter made from iron ore and other materials at ore agglomeration facilities. The pellets or sinter are charged with coke in the blast furnace, and hot blast air is blown through tuyeres in the lower part of the furnace. The hot gas from coke combustion creates a reducing atmosphere in which the iron oxides are converted and melted to molten pig iron. Metallic iron also can be produced without using coke in a direct reduction process, generating the necessary reducing atmosphere directly with coal or natural gas. Pig iron contains 3 to 4 percent carbon and direct-reduced iron commonly contains 1 to 3 percent carbon.

- **Steelmaking** removes carbon and other impurities by controlled oxidation of the iron charged into a steelmaking furnace. In addition to hot metal from a blast furnace, iron and steel scrap or direct-reduced iron can be charged into a steelmaking furnace. Additional elements, chromium or nickel for example, may be added to steel in the furnace or in the ladle after the furnace to produce special alloy steels. The principal steelmaking processes used in the US are:

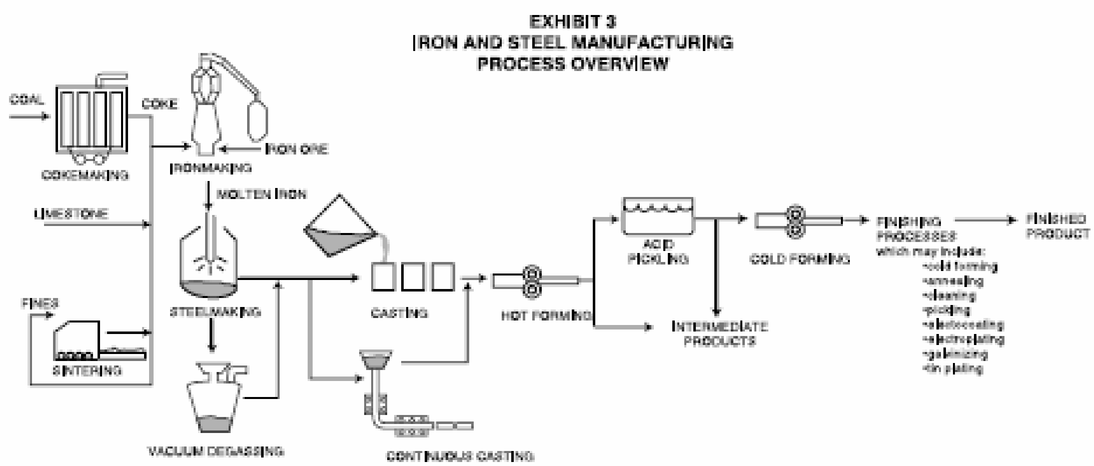
    - **Basic oxygen furnace (BOF)** – molten iron from the blast furnace is refined by injecting high purity oxygen and adding fluxing materials. BOF offers superior energy efficiency with high throughput. Steelmaking facilities that use this technology are supplied with molten iron from a blast furnace, along with up to 30 percent steel scrap. These facilities, which may also include a coke plant and finishing facilities, are collectively known as integrated mills.
    - **Electric arc furnace (EAF)** – steel scrap is melted and refined using electric energy, so no cokemaking or ironmaking operations are required.[30] EAF permits charging with high levels of scrap, which reduces or eliminates the need for access to hot metal from the blast furnace. Steel facilities that use this technology are referred to as mini mills.

---

[29] The following discussion of the basic iron and steelmaking process is summarized from two sources – EPA Sector Notebook on Iron and Steel, 1995, and Gas Research Institute, *Environmentally Driven Threats and Opportunities for Natural Gas in the Iron and Steel Industry*, (prepared by ICF/EEA), November 1994.
[30] Some EAF facilities use scrap substitutes (e.g., pig iron or direct reduced iron) as well as scrap.

- In the **Forming and Finishing** stage, once the molten steel has attained the desired chemical composition in the steelmaking furnace, it is tapped (poured) into a ladle. Additional chemical adjustment may occur in the ladle with the addition of alloying material or the removal of unwanted constituents from the molten steel. The next step is the casting of the molten steel. There are two types of casting used today: continuous casting and ingot casting. Continuous casting accounts for about 97 percent of total steel produced. In continuous casting, molten steel is shaped directly from the ladle to form semi-finished steel products known as blooms, billets, and slabs. These semi-finished steel products are rarely used as final products. They usually serve as raw materials in the manufacturing of final steel products. The semi-finished products undergo various processes including hot rolling, cold rolling, forging, and drawing to form the finished products.

Exhibit 8: Basic Iron & Steel Production Process



Source: EPA Sector Notebook

Exhibit 9 shows the relative share of the different fuel types used in the iron and steel sector in 2002. Coke and breeze generated in the manufacturing process was the dominant fuel source at 36 percent. The industry also used significant amounts of natural gas (27 percent). The “Other” fuel category (21 percent) was largely composed of byproduct fuels such as coke oven gas and blast furnace gas. (All of the coke and breeze and most of the fuels classified as "other" are coal-based in origin.)

Exhibit 9: Primary Fuel Inputs as Fraction of Total Energy Supply for the Iron & Steel Industry in 2002 (fuel use only)

Coal	Other*	Net Electricity	Natural Gas	Coke & Breeze*
3%	21%	13%	27%	36%

Source: *Energy Trends in Selected Manufacturing Sectors*, EPA Sector Strategies Division, March 2007, based on *DOE/EIA Manufacturing Energy Consumption Survey, 2002 Data Tables*. Totals may not add to 100 percent due to rounding.
Net electricity provides a rough approximation for purchased power and includes purchased electricity, transfers in, and generation from noncombustible renewables, and excludes electricity transferred out or sold.
**All of the coke and breeze, and most of the fuel inputs classified as "other" (i.e., byproduct fuels such as coke oven gas and blast furnace gas), are coal-based in origin.*

Air Emissions

The cokemaking process is a large source for air emissions, including fine particles of coke generated during the process and sulfur compounds emitted from the coke oven stacks. However, because the expulsion of volatile substances from coal is the purpose of cokemaking, fugitive VOCs are the most important source of air emissions. These emissions include various complex hydrocarbons, such as benzene and polycyclic aromatics, as well as other VOCs.

Ironmaking is also significant from an air pollution perspective, as it generates significant amounts of NOx, some SO_2, and particulates.[31] Air emissions are generated from the crushing and handling of the ore and from fuel combustion in the furnace. Ore crushing is the largest source of uncontrolled PM in the iron and steel industry. The emissions from crushing operations, while considerable, are effectively controlled by conventional PM technologies.

Steelmaking generates some amounts of NOx as a by-product of CO combustion in the exhaust of both furnaces. The EAF process also generates additional NOx at the arc. Emissions of VOCs and other pollutants depend on the quality of material charged into the furnace. VOC emissions are derived primarily from the scrap charge, which is greater in the EAF.

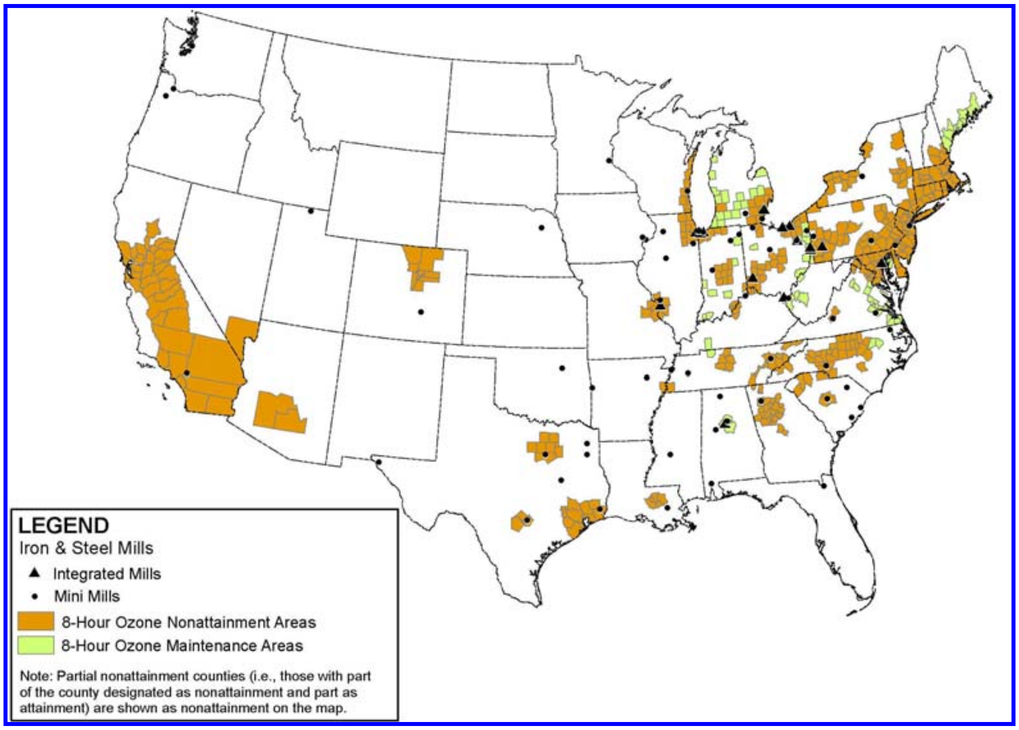
b. Location

There are currently 18 integrated steel mills operating in the U.S., mostly in the Great Lakes region. In addition, there are mini mills operating in approximately 70 locations across the country, with a large concentration in the Great Lakes region as well.[32] Exhibit 10 below presents the location of iron and steel mills in relation to nonattainment and maintenance areas for the current 8-hour ozone NAAQS, as of October 2007.[33] [34] Exhibit 11 presents the location

[31] *Energy and Environmental Profile of the U.S. Iron and Steel Industry*, US Department of Energy, Office of Industrial Technologies, August 2000.
[32] List of iron and steel facilities prepared by U.S. EPA Sector Strategies Division.
[33] The locations of iron and steel mills were obtained from the American Iron and Steel Institute. Data on nonattainment and maintenance areas for the current 8-hour ozone NAAQS were obtained from EPA's *Green Book: Nonattainment Status for Each County by Year*, October 2007, available at http://www.epa.gov/oar/oaqps/greenbk/map8hrnm.html and http://www.epa.gov/oar/oaqps/greenbk/anay.html.

of iron and steel mills in relation to counties violating the current 24-hour PM2.5 NAAQS, based on 2004-06 monitoring data.[35] While these exhibits indicate that a number of iron and steel mills are located in or near areas that currently violate the short-term standards for ozone or PM2.5, it should be noted that many of these areas are projected to attain the standards in the near term while other areas are at risk of violating the standards in the future. It should also be emphasized that source-specific factors, including process-level emissions, stack parameters, topography, meteorology and air chemistry, would need to be taken into account when assessing the air quality impact of any individual facility or sector on local or regional air quality problems.

Exhibit 10: Location of Iron and Steel Mills in Relation to 8-Hour Ozone Nonattainment and Maintenance Areas

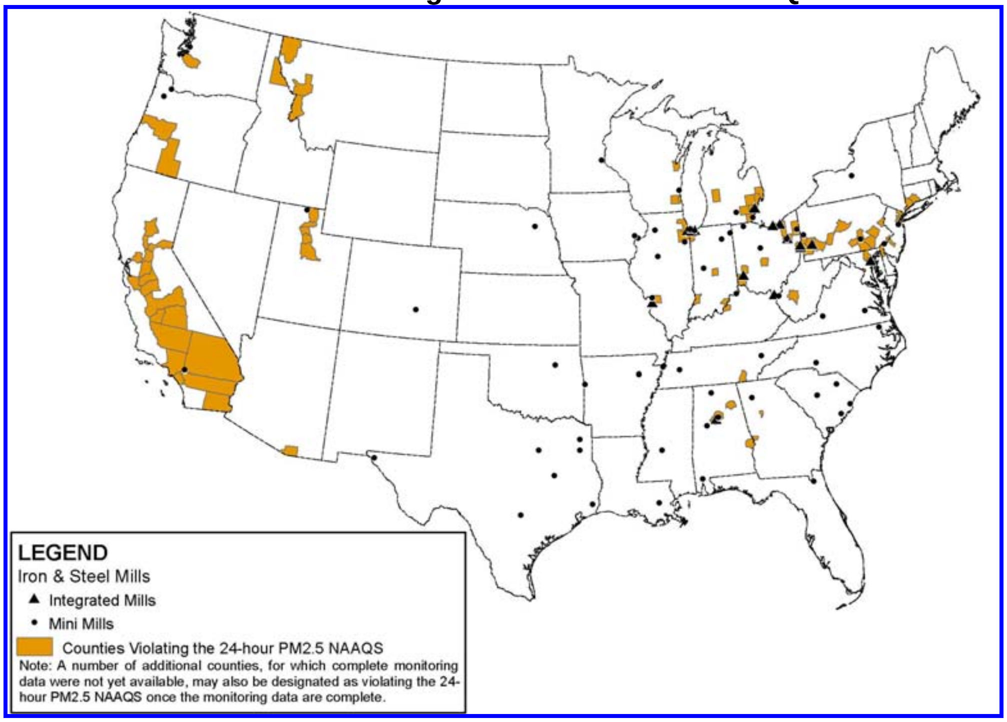


Sources: *Iron and steel mill locations obtained from U.S. EPA Sector Strategies Division. Nonattainment and maintenance areas for the current 8-hour ozone NAAQS obtained from EPA's Green Book: Nonattainment Status for Each County by Year, October 2007.*

[34] EPA proposed tightening the 8-hour ozone NAAQS on July 11, 2007. See: http://www.epa.gov/air/ozonepollution/pdfs/20070711_proposal_fr.pdf.

[35] The locations of iron and steel mills were obtained from the American Iron and Steel Institute. Data on counties violating the current 24-hour PM2.5 NAAQS were obtained from EPA's Air Quality System (AQS) as of July 11, 2007, available at http://www.epa.gov/airtrends/values.html.

Exhibit 11: Location of Iron and Steel Mills in Relation to Counties Violating the 24-Hour PM2.5 NAAQS



Sources: *Iron and steel mill locations obtained from U.S. EPA Sector Strategies Division. Counties violating the current 24-hour PM2.5 NAAQS (based on 2004-06 monitoring data) obtained from EPA's Air Quality System (AQS) as of July 11, 2007.*

c. Potential Episodic Control Measures

We focused our analysis on four categories of potential episodic control measures for the iron and steel sector:

- Fuel switching;
- Low cost retrofits and enhanced use of existing control equipment;
- Scheduling changes; and
- Dispatch changes.

i. Fuel switching

For integrated iron and steel mills that produce coke, little opportunity exists to switch from coal to other fuels in the coke-making process. Since coke-making is one of the most polluting processes in this industry, integrated mills may, however, reduce their reliance on coke by burning pulverized coal as an auxiliary fuel in the blast furnace. This would decrease the amount of coke they need to produce and yield a corresponding decrease in emissions from the coke-making process. There are technical limits, however, on the extent to which pulverized coal can be used to displace coke in a blast furnace. Moreover, once a mill has made the considerable capital investment necessary to use pulverized coal, it would be expected to use that fuel (which is less expensive than coke) to the maximum extent possible. Therefore, there appears to be little opportunity to increase the use of pulverized coal in a blast furnace as part of a strategy to reduce coke oven emissions on days with high air pollution concentrations. Some blast furnaces may, however, be able to use natural gas as an auxiliary fuel on an episodic basis. Using natural gas would likely result in NOx, SO_2, and PM emission reductions. More research is needed, however, to assess the economic and technical feasibility of this option.

Most boilers at integrated iron and steel mills are designed to burn multiple fuels and are able to switch among these fuels on a few hours notice. Consequently, another short-term fuel switching option that might hold some promise for reducing NOx, SO_2, and VOC emissions at integrated mills is to switch from coke oven gas to natural gas in boilers on days with high air pollution concentrations. Most integrated mills have some capability to store unused coke oven gas but must flare any unused gas that they are unable to store.[36] Depending on the storage capacity of their gas holders, and how much of that capacity is unutilized at the time, mills may be able to increase the use of natural gas in their boilers for a limited period of time, while saving the displaced coke oven gas for later use. As discussed below, mills may also be able to slow the operation of their coke ovens as part of an episodic control strategy, which would decrease the amount of coke oven gas that is available for use in the boilers. This shortfall could then be made up by burning more natural gas. Further analysis is needed to determine the extent to which integrated mills could shift from coke oven gas to natural gas in boilers, and the degree to which such shifts would reduce NOx, SO_2, and VOC emissions.[37] Emission and cost impacts would need to be assessed on a plant-by-plant basis.

Because mini mills do not have any significant fuel needs and depend primarily on grid-supplied electricity, there do not seem to be any fuel switching options for mini mills.

Summary: Fuel Switching

Integrated mills may be able to temporarily slow down the coke-making process to decrease coke oven emissions and decrease the supply of coke oven gas to the boilers. The boilers could compensate by burning more natural gas which would result in reduced boiler emissions of NOx, SO_2, and VOC. There may also be opportunities to store a limited amount of coke oven gas in gas holders, which would enable mills to temporarily increase their use of natural gas at boilers while saving the displaced coke oven gas for later use.

Some integrated mills may also be able to use natural gas as an auxiliary fuel in the blast furnace to achieve short-term reductions in NOx, SO_2, and PM emissions. This could also allow for a temporary decrease in coke production and a corresponding decrease in emissions from the coke-making process.

These potential fuel switching options for integrated mills need to be studied at the plant-level, as their infrastructural needs, operational impacts and subsequent costs may vary by plant.

No fuel switching options were identified for mini mills.

[36] Indications are that most integrated mills may have gas holders to store limited quantities of unused coke oven gas (e.g., one or two days supply).
[37] Our initial discussions with industry analysts seemed to point towards a significant emission reduction benefit if mills were to switch from coke oven gas to natural gas.

ii. Low-cost retrofits and enhanced use of existing control equipment

Another set of episodic control measures we considered entails the use of add-on control equipment. Although most pollution control retrofits require significant capital expenditure for installation, there are some controls that have relatively low installation costs but higher operation and maintenance (O&M) costs. Such low-capital, high O&M retrofits may be cost-effective to operate for short periods when high air pollution concentrations occur. Similarly, where control technologies are already deployed, it may be possible to run them more aggressively for short intervals, or in other ways that would not be feasible or cost-effective on a continuous basis.

- We identified one control technology that seemed to have potential as an episodic control measure for iron and steel mills: Selective Non-Catalytic Reduction (SNCR).

SNCR for NOx Control

Some analysts we spoke with felt that SNCR may hold promise as a short-term control measure for reducing NOx emissions from integrated iron and steel mills. While SNCR technology has been in use for many years in some industries, no SNCR system has yet been installed at an iron or steel mill. The limiting factor has been the cost of implementing these systems.

According to industry analysts and technology vendors, the cost of purchasing and installing an SNCR system may be on the order of $1 million or more for a large industrial boiler. However, for large boilers, most of the total annualized cost associated with an SNCR system is for the reagent used (urea or aqueous ammonia). Therefore, the cost burden associated with installing and operating an SNCR system could be reduced significantly under an episodic control program. For example, in the case of a large boiler it might be possible to reduce the total cost burden of an SNCR system by 50 percent or more if the system were installed and run at an intermediate (e.g., 30 percent) control level on a continuous basis, and then ramped up to full capacity (e.g., 50 percent control efficiency) on days with high air pollution concentrations. The cost burden could be further reduced if the SNCR system were kept on standby and used only on days with high air pollution concentrations.

A major concern expressed by industry analysts was that once an SNCR system is installed and available for use as part of an episodic control program, regulators and/or community activists may demand that it be run at full capacity on a continuous basis. Further analysis of the costs of this option and other site-specific considerations is required.

Summary: Low Cost Retrofits and Enhanced Use of Existing Control Equipment

Some analysts felt that an SNCR system may hold promise as an episodic control measure for reducing NOx emissions from large boilers at integrated mills and warrants further research. Because of the relatively low capital cost and the ability to limit reagent consumption, installing and using SNCRs as part of an episodic control program may be a cost-effective strategy for this industry.

iii. Scheduling changes

Integrated mills

Industry analysts felt there might be opportunities to curtail cokemaking operations at integrated facilities for short periods in order to reduce VOC, NOx, SO_2, and PM emissions. Facilities can generally lengthen the coking cycle (e.g., from 16 hours to up to 24 hours) without disrupting other parts of the production process, where they have sufficient onsite coke inventories or the ability to buy additional coke from merchant coke manufacturers. There is indication that some facilities may already have permit provisions that require them to use longer coking cycles in response to upset conditions. As discussed above, slowing down the coking cycle would also reduce the production of coke oven gas, allowing facility operators to increase the use of natural gas in boilers, which would yield additional NOx, SO_2, and VOC emission reductions.

Integrated facilities might also be able to increase scrap usage in the basic oxygen furnace for short periods of time and on short notice. Basic oxygen furnaces typically charge between 10 and 30 percent scrap, with the permissible range varying from product to product. Within this range, the choice of hot metal versus scrap is primarily based on price. Therefore, there may be limited opportunity at some mills to temporarily shift to a higher scrap utilization rate within the permissible range for a product, or to switch to production of a product that permits a higher scrap utilization rate.

Another possible option would be to slow down or delay batch operations in the blast furnace for short intervals. Industry analysts emphasized, however, that operational stability is very important for blast furnaces. For this and other reasons, they believed that episodic control measures that target scheduling changes in coke oven operations and/or increased scrap utilization rates in the basic oxygen furnace may hold more promise for integrated steel mills than scheduling changes affecting the blast furnace.

Options for rescheduling production activities at integrated mills need to be assessed with regard to their potential costs and emission reduction benefits, and evaluated further with plant operators to understand their effectiveness and the tolerable levels of disruption for integrated mills.

Mini mills

Because mini mill operation is generally batch in nature, there may be opportunities to rearrange production schedules on a short-term basis to move high emitting processes to times when they are less likely to exacerbate air quality problems. For example, rescheduling melting operations from daytime to nighttime hours could significantly reduce emissions of VOC and NOx during critical daylight hours when ozone formation occurs. Similarly, rescheduling melting operations from one time period to another could potentially shift PM and NOx emissions to a period when those emissions would be less likely to contribute to a PM2.5 violation.

Since mini mills consume extremely large amounts of grid-supplied electricity, rescheduling melting operations could be particularly useful on high electricity demand days when electric utilities may utilize very high-emitting generating units to meet peak load requirements. Shifting mini mill electricity consumption from daytime to nighttime hours (when lower-emitting generating capacity is available and the resultant emissions may have less ozone or PM2.5 forming impact), could therefore provide significant air quality benefits.

Note that during the rolling blackouts in California in 2001 and 2005 (see the Appendix), some mini mills with interruptible power contracts switched to firm contracts with their power suppliers because the power curtailments were deemed too costly. Others, however, rescheduled their melting operations to off-peak hours to take advantage of the cheaper electricity rates during those times and still allow for the interruptible contracts to continue.[38]

[38] Mini mills pointed out that an unscheduled stoppage that occurs during the course of the melting operation is extremely dangerous to workers and could cause equipment destruction.

According to industry analysts, many mini mills in other parts of the country also have interruptible power contracts so that electricity can be temporarily curtailed or halted when there is a surge in electricity demand. There is also evidence that some mills in other parts of the country run at night to take advantage of cheaper off-peak electricity rates.

Further analysis is needed to determine the extent to which mini mills may have additional opportunities to shift production to off-peak electricity generation periods, and the magnitude of the SO_2 and NOx emission reductions that such short-term scheduling changes could provide. Further analysis is also needed to more fully assess the cost and operational impacts of these changes on individual facilities.

Summary: Scheduling Changes

Integrated steel mills might be able to implement longer coking cycles for short time periods if they have adequate onsite coke inventories or access to merchant coke. These mills may also be able to increase the use of scrap in their basic oxygen furnaces. Scheduling changes in blast furnaces, while technically feasible, appear to be more disruptive for these facilities.

Due to the batch nature of mini mill operations, many mini mills already use interruptible power contracts, or schedule their melting activities during off-peak hours, and there may be opportunities to make additional scheduling changes to shift melting and other high emitting processes to times when they would be less likely to exacerbate air quality problems. The deferral of melting operations from daytime to nighttime hours could be particularly useful on high electricity demand days, since it may enable utilities to avoid the use of very high-emitting generating units that would otherwise be needed to meet peak load requirements.

iv. Dispatch changes

According to industry analysts, most integrated steel mills have at least two boilers with some flexibility to shift load from one boiler to another on just a few hours notice. Analysts expressed their doubts on whether such a change in boiler dispatch would be worthwhile, however, since all boilers typically have the capability to use all the available fuel types, and fuel switching within the same boiler may generally be a more effective option.

Summary: Dispatch Changes

Because integrated mills have access to multiple boilers, changing boiler dispatch may be theoretically possible, but may not be practically effective. Most boilers can use all available fuel types, so switching fuel within the same boiler may be more effective than changing boiler dispatch.

d. Opportunity Assessment of Potential Episodic Control Options

Exhibit 12 summarizes the potential viability of the four primary options for further reducing emissions on days with high air pollution concentrations.

Exhibit 12: Opportunity Assessment – Iron & Steel

Option	Viability as Potential Episodic Control Measure
Fuel switching	**Promising** – Several short-term fuel switching options appear to have potential at integrated facilities (for NOx, SO_2, PM, and VOC reductions), but coke oven gas storage options, and the ability to link slowdowns in the coke-making process with increased use of natural gas at boilers, need to be evaluated **Unlikely** – At mini mills
Low cost retrofits and enhanced use of existing control equipment	**Promising** – SNCR on large boilers (for NOx reductions)
Scheduling changes	**Promising** – For both integrated facilities and mini mills
Dispatch changes	**Needs Further Study** – While it is likely that some integrated facilities could shift load among boilers on short notice, it is unclear if this would be an effective control measure

III. Cement

a. Overview of the Cement Manufacturing Process and its Emissions

Cement manufacturing requires the "thermochemical processing of substantial amounts of limestone, clay, and sand in large kilns" at very high and sustained temperatures (over 2,750°F) to produce an intermediate product called clinker.[39] Clinker is ground up with small quantities of gypsum to create Portland cement, the predominant variety of cement manufactured in the U.S. Portland cement is used as a binding agent in virtually all concrete.[40] The process of Portland cement manufacturing can be broken down into the following four steps:[41]

- Quarrying and crushing the rock;
- Grinding the carefully proportioned materials to high fineness;
- Subjecting the raw mix to thermochemical processing in a kiln; and
- Grinding the resulting clinker to a fine powder.

Cement is manufactured in four different types of kilns:[42]

- Long wet kilns;
- Long dry kilns;
- Dry kilns with preheaters; and
- Dry kilns with precalciners.

Processes that take place within each kiln type include drying and preheating, which comprises evaporation of free water, dehydration of clay minerals, and increasing the temperature of the raw materials to over 1,650 °F; calcining, a process of decomposing the carbon compounds, which occurs when the raw materials reach about 1,650 °F; and heating the calcined raw materials to about 2,750 °F, where they are sintered to form clinker. The same raw materials are used in the wet and dry kilns, however, the moisture content and processing techniques differ, along with kiln designs.[43]

- Wet process kilns are generally longer to allow them to dry the wet raw material mix (also known as slurry) as it is fed into the kiln.
- Long dry kilns are more energy efficient than wet process kilns but produce exit gases at very high temperatures.
- Preheater kilns differ from the traditional long wet and long dry kilns because they have a series of cyclones where the dry raw material is intimately mixed with the hot combustion gases. These kilns use about half of the fuel that a wet kiln uses to produce clinker because the preheater system efficiently recovers process heat.

---

[39] *Assessment of Control Technology Options for BART-Eligible Sources*, prepared by NESCAUM, March 2005.

[40] *Energy Trends in Selected Manufacturing Sectors*, prepared by ICF for EPA's Sector Strategies Division, March 2007.

[41] *Assessment of NOx Emissions Reduction Strategies for Cement Kilns – Ellis County – Final Report*, prepared for Air Quality Planning Section, Texas Commission on Environmental Quality, July 14, 2006.

[42] *Ibid.*

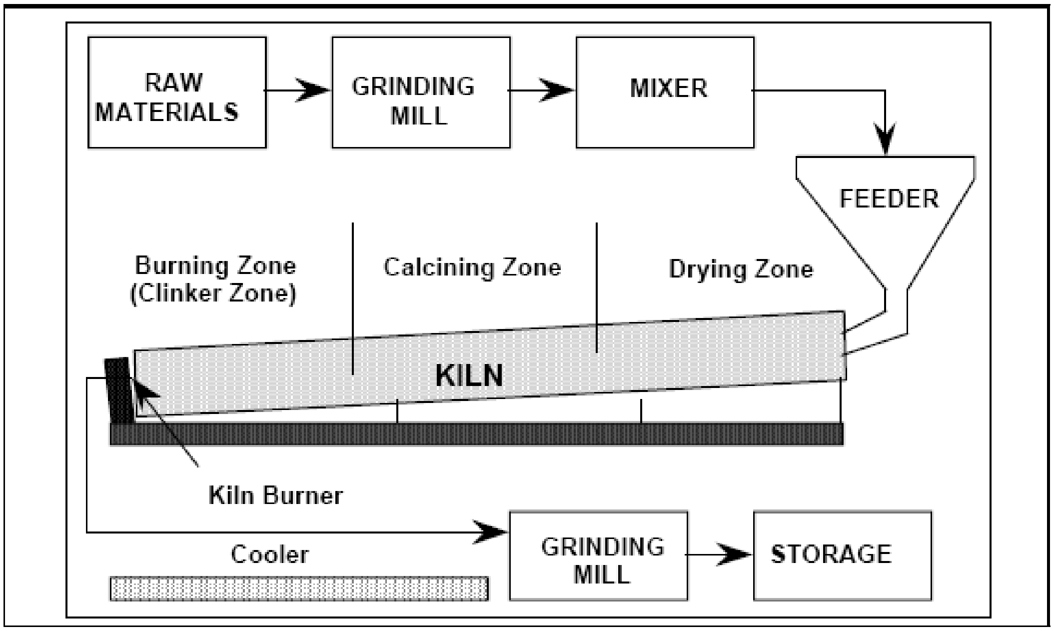
[43] The following description of the cement manufacturing process and emissions profile is taken from the EPA Sector Notebook on Stone, Clay, Glass, and Concrete Products Industry (including cement), September 1995.

- Precalciner kilns have a calciner vessel inserted between the preheater and the kiln. In a precalciner kiln about 40 percent of the fuel is fired in the kiln and the rest is fired in the calciner. Firing a large amount of the fuel in the calciner significantly reduces thermal NOx emissions because the fuel is burned at less than 2,000^{o}F and normally fuel consumption for a precalciner kiln is 10 percent less than a preheater kiln.

The clinker produced in the kiln is cooled in a traveling grate using ambient air and the cooled clinker is transferred to storage. The clinker is then mixed with four to six percent gypsum and ground to produce a homogeneous cement powder, which is typically sent to a bulk storage area and then shipped by truck or rail.

Exhibit 13 presents a simple flow diagram of the traditional cement production process using a long wet kiln.

Exhibit 13: Basic Cement Production Process



Source: *Report to Congress on Cement Kiln Dust (obtained from the EPA Sectors Notebook, September, 1995)*.

Exhibit 14 shows the relative shares of the different fuel types used in the cement sector in 2002. Coal was the dominant fuel at about 58 percent of the total, not only because it was relatively inexpensive but also because the resulting coal ash contains minerals that chemically combine with the raw material to make clinker. The "Other" fuel category included petroleum coke as well as waste materials that were incinerated for fuel, such as tire derived fuel (TDF). Tires made up 3 percent of the total fuel use by this sector in 2004.[44]

[44] See Table 22 in *Energy Trends in Selected Manufacturing Sectors,* EPA Sector Strategies Division, March 2007.

Exhibit 14: Primary Fuel Inputs as Fraction of Total Energy Supply for the Cement Industry in 2002 (fuel use only)

Coal	Other	Net Electricity	Natural Gas	Coke & Breeze
58%	23%	11%	5%	2%

Source: *Energy Trends in Selected Manufacturing Sectors*, EPA Sector Strategies Division, March 2007, based on *DOE/EIA Manufacturing Energy Consumption Survey, 2002 Data Tables*. Totals may not add to 100 percent due to rounding.
Net electricity provides a rough approximation for purchased power and includes purchased electricity, transfers in, and generation from noncombustible renewables, and excludes electricity transferred out or sold.

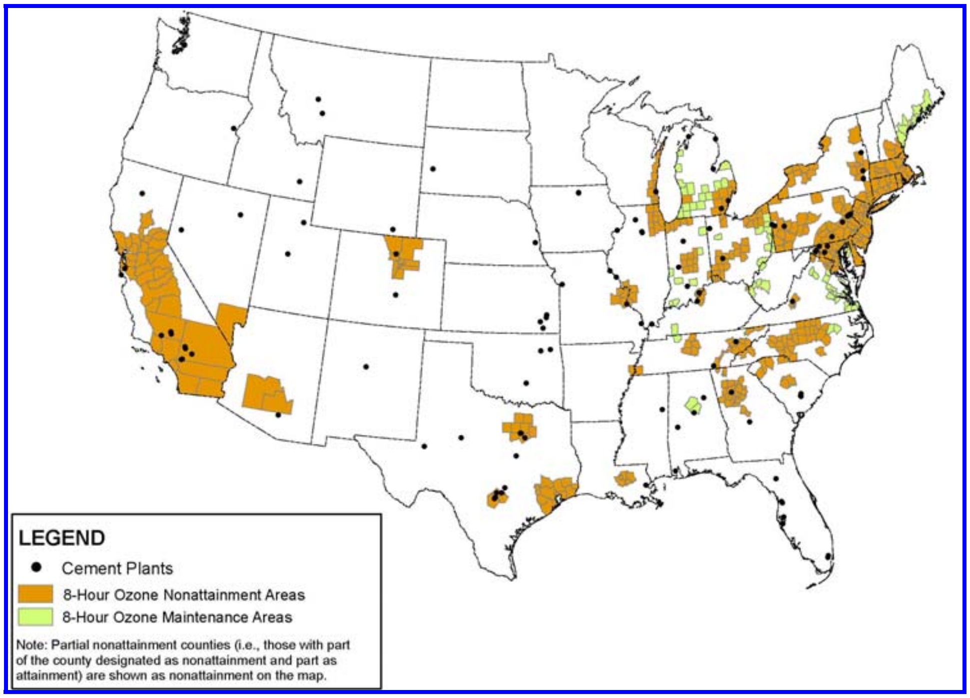
Air Emissions
The largest emission source within cement plants is the kiln operation, which includes the feed system, preheater or precalciner (for preheater/precalciner kiln systems), the fuel firing system(s), the actual kiln, and the clinker cooling and transport system. The kiln generates NOx, SO_2, CO, and hydrocarbon emissions. NOx emissions are from the combustion of fuels to dry, calcine, and clinker the raw materials. The emissions of CO, SO_2 and hydrocarbons are primarily derived from organic and pyretic sulfur in the raw materials. Sources of particulate emissions include raw material storage, grinding and blending, clinker production, finish grinding, and packaging.

b. Location

There were 114 cement plants located in 37 states in 2005. Regionally, cement production was concentrated in six states – California, Texas, Pennsylvania, Michigan, Missouri, and Alabama – which accounted for approximately one-half of U.S. production.[45] Exhibit 15 below presents the location of cement plants in relation to nonattainment and maintenance areas for the current 8-hour ozone NAAQS, as of October 2007.[46] [47] Exhibit 16 presents the location of cement plants in relation to counties violating the current 24-hour PM2.5 NAAQS, based on 2004-06 monitoring data.[48] While these exhibits indicate that a number of cement plants are located in or near areas that currently violate the short-term standards for ozone or PM2.5, it should be noted that many of these areas are projected to attain the standards in the near term while other areas are at risk of violating the standards in the future. It should also be emphasized that source-specific factors, including process-level emissions, stack parameters, topography, meteorology and air chemistry, would need to be taken into account when assessing the air quality impact of any individual facility or sector on local or regional air quality problems.

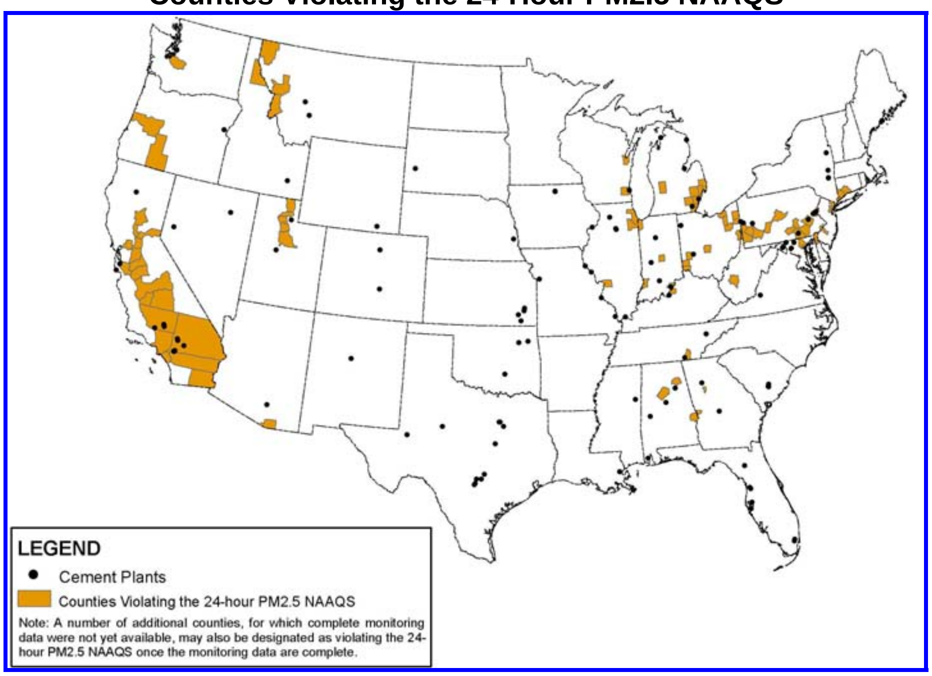
[45] See Cement Profile in *Sector Strategies Performance Report 2006*, U.S. EPA Sector Strategies Division, available at www.epa.gov/sectors/performance.html.
[46] The locations of cement plants were obtained from *PIS Plant Directory, U.S. Cement Plants*, December 2002. Data on nonattainment and maintenance areas for the current 8-hour ozone NAAQS were obtained from EPA's *Green Book: Nonattainment Status for Each County by Year*, October 2007, available at http://www.epa.gov/oar/oaqps/greenbk/map8hrnm.html and http://www.epa.gov/oar/oaqps/greenbk/anay.html.
[47] EPA proposed tightening the 8-hour ozone NAAQS on July 11, 2007. See: http://www.epa.gov/air/ozonepollution/pdfs/20070711_proposal_fr.pdf.
[48] The locations of cement plants were obtained from *PIS Plant Directory, U.S. Cement Plants*, December 2002. Data on counties violating the current 24-hour PM2.5 NAAQS were obtained from EPA's Air Quality System (AQS) as of July 11, 2007, available at http://www.epa.gov/airtrends/values.html.

Exhibit 15: Location of Cement Plants in Relation to 8-Hour Ozone Nonattainment and Maintenance Areas



Sources: *Cement plant locations obtained from PIS Plant Directory, U.S. Cement Plants, December 2002. Nonattainment and maintenance areas for the current 8-hour ozone NAAQS obtained from EPA's Green Book: Nonattainment Status for Each County by Year, October 2007.*

Exhibit 16: Location of Cement Plants in Relation to Counties Violating the 24-Hour PM2.5 NAAQS



Sources: *Cement plant locations obtained from PIS Plant Directory, U.S. Cement Plants, December 2002. Counties violating the current 24-hour PM2.5 NAAQS (based on 2004-06 monitoring data) obtained from EPA's Air Quality System (AQS) as of July 11, 2007.*

c. Potential Episodic Control Measures

We focused our analysis on four categories of potential episodic control measures for the cement sector:

- Fuel switching;
- Low-cost retrofits and enhanced use of existing control equipment;
- Scheduling changes; and
- Combustion reoptimization.

i. Fuel switching

We analyzed three potential short-term fuel switching opportunities: (a) increasing the use of tire derived fuel (TDF); (b) partially replacing coal with used oil, waste solvents or other alternative liquid fuels; and (c) partially replacing coal with natural gas.

Increasing TDF usage
According to industry experts, burning TDF at cement kilns by means of mid-kiln injection can reduce NOx emissions by as much as 20 to 40 percent.[49] Moreover, TDF can be stored easily by most cement plants in closed trailers onsite. Hence, we considered whether there was any potential to increase TDF usage rates on an episodic basis to reduce NOx emissions and help communities meet their ozone and/or PM2.5 attainment goals.

Currently, about 25 percent of the kilns in the U.S. are configured to use TDF as an alternative fuel source. These kilns typically burn anywhere between 10 and 20 percent of their total fuel in TDF, with the upper limit determined through existing permit requirements. Most of these kilns, however, appear to use TDF below their maximum permitted levels, as well as below their physical TDF burning capacities, due to cost and availability considerations. Hence, these kilns have some potential for increasing their TDF feed rates.

Most industry analysts agreed, however, that because of the complex chemistry of the kiln operation, making short-term changes to the TDF feed rates could have a negative impact on the clinker chemical composition and may require other changes in the production process. In addition, kilns typically operate under “steady-state” conditions, and short-term deviations due to changes in the fuel mix can make them less efficient, thereby requiring more energy to operate at the optimum level. Short-term changes in the fuel mix can also cause kiln upsets. Additional energy consumption or a kiln upset could result in a corresponding increase in air emissions which could undermine or erode the emission reduction benefits associated with greater TDF usage.

Moreover, some analysts believed that the NOx emission reduction resulting from each incremental unit of TDF burned in a kiln is likely to be less than the reduction that resulted from the previous unit of TDF burned (that is, the relationship between increased use of TDF and its associated emission reduction benefit may be nonlinear with diminishing returns). Increasing TDF burn rates from current levels could, therefore, give rise to less than proportional

[49] See also *SCAQMD Expects Tires to Reduce NOx Emissions*, available at www.wbcsd.ch/web/projects/cement/tf2/tires.pdf.

reductions in NOx emissions, making the additional TDF consumption less useful as an episodic pollution control strategy.[50]

Switching from coal to used oil or solvents

Another short-term fuel switching option that we investigated involves the introduction of a limited quantity of used oil, waste solvent or other alternative liquid fuel to replace existing coal used in a kiln.

Most analysts thought it might be possible to replace 5 to 15 percent of the coal burned in a kiln with used oil without significantly altering the steady-state chemistry in the kiln. A switch from coal to used oil of this magnitude could potentially produce significant incremental NOx reductions – particularly if the first displaced units of coal yield a disproportionate NOx emission reduction benefit. A fuel switch of this magnitude could also yield some incremental SO_2 emission reductions. Similar emission reductions may also be achievable by displacing a limited amount of the coal burned in a kiln with waste solvents or tar. The introduction of waste solvents, tar or other alternative liquid fuels could, however, trigger the need for lengthy and contentious permit revisions, and it could be difficult to justify such revisions where the fuels in question would only be used for short intervals. For this reason, used oil may be a better candidate for fuel switching as part of an episodic control strategy, particularly in cases where a cement plant is already set up and permitted to burn used oil and has one or more dormant oil tanks.

Switching from coal to natural gas

A final short-term fuel switching option we considered was to partially replace the coal burned in precalciners with natural gas. According to industry analysts, typically 50-60 percent of the fuel consumed by cement plants with precalciner kilns is burned in the precalciner, and coal is the predominant fuel utilized. Unlike the kiln itself, where switching from coal to natural gas would likely increase NOx emissions, displacing some of the coal burned in the precalciner with natural gas would be expected to yield NOx emission reductions. However, the coal used in different precalciners may contain different amounts of nitrogen (generating NOx after combustion), and so this fuel switching option may be of limited utility as a NOx reduction strategy at facilities that already burn coal with relatively low nitrogen content.[51]

A major concern expressed by industry analysts regarding this fuel switching strategy was that replacing a large percentage of the coal burned in a precalciner with natural gas could alter the chemical composition of the clinker (e.g., by reducing the coal ash content), thereby raising quality concerns regarding the final product. It may, however, be possible to replace coal with natural gas on a more limited basis without raising product quality concerns. This requires further analysis.

---

[50] One option that appears to be worth considering is to increase the *number* of kilns that are permitted to burn TDF. Technically, this seemed to be a viable option, especially for the preheater/precalciner kilns, most of which are currently not permitted to burn TDF. While permitting more kilns to burn TDF cannot be considered an episodic control strategy, this strategy may hold promise for the ultimate goal of pollution reduction in nonattainment areas.

[51] An alternative to replacing coal with natural gas could be to replace coal with liquid petroleum gas (LPG), which would be easier to store onsite than natural gas. While most analysts we spoke with did not raise any immediate concerns with this type of fuel switch, further studies need to be conducted to determine its viability.

Industry analysts noted that given the high price of natural gas, switching from coal to natural gas on a *continuous* basis would be prohibitively expensive. However, since this strategy involves only short-term substitution of a limited portion of the coal used in the precalciner, and since it would require very low capital expenditures, it may prove to be more cost-effective than other available alternatives. However, site-specific costs, access to natural gas supplies and other facility-specific factors would need to be taken into consideration in order to determine whether this can be a viable episodic control strategy.

Summary: Fuel Switching

Overall, large scale fuel switching measures to reduce emissions from cement kilns on an episodic basis seem to have little potential.

- The biggest concern expressed by industry analysts was the importance of maintaining the steady-state nature of kiln operations which minimizes kiln upsets and related emission increases, and the optimum fuel mix to drive kiln efficiency.
- A related concern was that the quality of the final product was dependent on the complex chemistry inside the kiln; changing fuels on short notice may alter the chemical composition of the final product.

Our discussions with industry analysts did, however, indicate there may be potential to replace a limited portion (e.g., 5 to 15 percent) of the coal burned in a cement kiln with used oil, and a limited portion of the coal burned in a precalciner with natural gas. These relatively small scale fuel switches could potentially yield additional SO_2 and NOx reductions without disrupting the steady-state production process or the chemistry in the kiln, although the magnitude of the pollution reductions would need to be analyzed to determine their significance. These options require further analysis.

ii. Low-cost retrofits and enhanced use of existing control equipment

Another set of episodic control measures we considered entails the use of pollution control equipment, such as post-combustion control technologies. Although most pollution control retrofits require significant capital expenditure for installation, there are some that have relatively low installation costs but higher O&M costs. Such low-capital, high O&M retrofits may be cost-effective to operate for short time periods during an episodic event. Similarly, where control technologies are already deployed, it may be possible to run them more aggressively for short intervals, or in other ways that would not be feasible or cost-effective on a continuous basis.

- One control technology that seemed promising from the standpoint of achieving further short-term NOx reductions was Selective Non-Catalytic Reduction (SNCR). [52]
- Another promising control option from the standpoint of achieving further short-term SO_2 reductions was the use of lime injection techniques, including micro-fine lime addition.

SNCR for NOx Control

Analysts felt that SNCR may hold some promise as an episodic control strategy for reducing NOx emissions from preheater/precalciner kilns in the cement industry. SNCR technology has been in use for many years. To date, however, fewer than ten cement plants have installed an SNCR system. While there are indications that some state and local air quality regulators may

[52] Another NOx control technology that might be viable for the cement sector is gas reburn. Industry analysts pointed out there is no data on gas reburn in the cement sector. However, because gas reburn may be a viable strategy for episodic NOx reductions in other sectors, it warrants further study with respect to the cement sector as well.

be considering the imposition of SNCR control requirements where further NOx emission reductions are needed to achieve air quality goals, the limiting factor to date has been the cost of implementing these systems.

According to industry analysts and technology vendors, the cost of purchasing and installing an SNCR system may be on the order of $1 million for a typical mid-sized kiln. However, for most large applications such as cement kilns, the majority of the total annualized cost associated with an SNCR system is for the reagent used (urea or aqueous ammonia). Therefore, the cost burden associated with installing and operating an SNCR system could be reduced significantly under an episodic control program. For example, it might be possible to reduce the total cost burden of an SNCR system by 50 percent or more where the system is installed and run at an intermediate control level on a continuous basis and then ramped up to full capacity on days with high air pollution concentrations. Even greater cost reductions may be possible where the system is kept on standby and used only on days with high air pollution concentrations.

A major concern expressed by industry analysts was that once an SNCR system is installed and available for use as part of an episodic control program, regulators and/or community activists may demand that it be run at full capacity on a continuous basis. Further analysis of the costs of this option and other site-specific considerations is required.

For those cement plants that have already installed an SNCR system, an alternative strategy may be to increase their utilization rates for short time periods when high air pollution concentrations occur. Although we were not able to conclusively determine whether there is room for increased utilization at facilities with existing SNCR systems, this strategy may warrant further exploration with regulators, plant managers and equipment vendors.

Lime injection for SO_2 Control

Cement plants may have the ability to use lime injection to get additional cost-effective SO_2 removal on a short-term basis. Since most cement plants using a preheater or precalciner system already have spray cooling and conditioning towers, the additional costs associated with lime injection would be less than for wet or long dry kilns. Further research is needed to determine the extent to which lime injection could achieve further SO_2 reductions on an episodic basis, and the cost of implementing this approach. Site-specific factors would need to be taken into consideration as well.

Micro-fine lime addition for SO_2 Control

Micro-fine lime addition involves the use of a very fine grind lime to absorb SO_2 in the exhaust stream of a kiln. The micro-fine lime is converted into a slurry (water suspension of lime) and injected into the water that is used in a spray cooling and conditioning tower that is connected to a bag house or ESP. The capital costs for retrofitting a cement plant to use micro-fine lime addition could be relatively small where a facility already has a spray cooling and conditioning tower in place, as is the case with most preheater/precalciner kilns. There would, however, be some capital costs to purchase and install equipment needed to store the micro-fine lime reagent onsite and for other equipment modifications. However, the major cost associated with micro-fine lime addition is the relatively high cost of the reagent itself, which makes it unsuitable for use as a continuous control strategy for cement kilns.

Evidence of micro-fine lime addition's use in the cement industry is limited, with its use to date restricted to precalciner kilns. Its primary function has been either to serve as a backup SO_2 control measure, e.g., to meet permit limits during short periods when the raw mill is not in operation, or to address detached plume/plume opacity issues created by condensing ammonia salts. When the raw mill is operating it serves as a *de facto* scrubber capable of removing as much as 80 to 90 percent or more of the SO_2. (Similar SO_2 removal efficiencies are typical with the operation of other types of kilns.) Nonetheless, our discussions with industry analysts indicated there might be opportunities to use micro-fine lime addition to achieve additional SO_2 reductions at precalciner kilns even when the raw mill is operating, as well as at other types of kilns. According to its manufacturer, micro-fine lime addition could be expected to further reduce SO_2 emissions from cement plants by 50 to 75 percent. This technology should be evaluated further to determine its viability and cost as an episodic control measure.

Summary: Low Cost Retrofits and Enhanced Use of Existing Control Equipment

Most analysts agreed that installing an SNCR system on preheater/precalciner kilns may have promise as an episodic control strategy for reducing NOx emissions and warrants further research. Because of the relatively low installation costs and the limited use of reagent, installing and using SNCR systems as part of an episodic control program may be a cost-effective strategy for preheater/precalciner kilns in this industry.

For those cement plants that have already installed an SNCR system, an alternative strategy may be to increase their utilization rates for short time periods during an episodic event. Although we were not able to conclusively determine whether there is room for increased utilization at facilities with existing SNCR systems, this strategy may warrant further exploration.

The use of lime injection or micro-fine lime addition to achieve additional SO_2 reductions at cement kilns should also be evaluated further to determine their viability and costs as episodic control strategies.

iii. Scheduling changes

We considered two types of short-term scheduling changes for the cement industry:

- First, we considered short-term changes in the clinker production schedule that could be undertaken to achieve additional emission reductions on a limited number of days when high air pollution concentrations occur. An example of such a schedule change is the curtailment of kiln operations for short periods.
- The second type of scheduling change relates to cement manufacturing activities that are ancillary to, and independent of, the actual clinker production process.

Changes to the clinker production schedule

Industry analysts indicated that while kiln operations could be curtailed on short notice (e.g., by slowing the rotation of the kiln to reduce its production rate), cement plants, which have been operating near full capacity in recent years, may be unable to make up the foregone production. Moreover, kilns that operate at optimum efficiency generally have the lowest emissions intensity (i.e., emissions per unit of clinker produced). Therefore, short-term changes to the optimum production rate can be counter-productive to emission reduction goals, eroding the short-term emission reduction benefits resulting from a slowdown while increasing the plant's total annual emissions.

Scheduling changes related to ancillary activities

Activities that are ancillary to the operation of a cement kiln include quarrying, running the finishing mill and bagging/loading the finished product. In addition to their direct emissions impact, these ancillary activities require electricity, and most cement kilns depend on grid-supplied electricity for these activities. Therefore, episodic control measures that curtail these operations for short periods of time can provide secondary emission reductions by temporarily reducing demand for electricity.

- ***Defer quarrying activities:*** Quarrying activities at cement plants can potentially be deferred to reduce PM and NOx emissions from diesel equipment, as well as the demand for grid-supplied electricity, on days with high air pollution concentrations. According to industry analysts, some facilities already conduct quarrying activities at night (for example, in response to interruptible electricity contracts, or to take advantage of cheaper off-peak electricity rates), and there may be additional opportunities to defer quarrying activities until nighttime hours as an episodic control measure. Other facilities may be able to curtail daytime quarrying activities when high air pollution concentrations occur by using existing stockpiles. These relatively low-cost strategies could be particularly useful on high electricity demand days when electric utilities may rely on relatively high emitting generating units in order to meet peak-day demand. Curtailing peak-day electricity consumption, or shifting that consumption from daytime to nighttime (when lower-emitting generating capacity is available and the resultant emissions may have less ozone or PM2.5 forming impact), could provide significant air quality benefits.

- ***Defer operation of finishing mill:*** The finishing mill uses the clinker generated by the kiln to produce the finished product sold to buyers. Finishing mills require electricity, and there is evidence that some mills run at night to take advantage of cheaper off-peak electricity rates, and others operate under interruptible electricity contracts so that they can be temporarily halted when there is a surge in electricity demand. Thus, some cement plants may be able to defer running the finishing mill in order to reduce electricity demand when high air pollution concentrations occur. As discussed above, this strategy could be particularly useful on high electricity demand days when electric utilities may rely on very high-emitting generating units in order to meet peak-day demand. The extent to which operations at a finishing mill can be deferred depends, however, on the facility's storage capacity and the extent to which the mill has excess grinding capacity to make up the lost production.

- ***Defer bagging/loading:*** Another ancillary activity that we considered with regard to short-term schedule changes relates to plant bagging and bulk loading processes. Changes in bagging and bulk loading schedules have the potential to defer electrical demand to off-peak hours, along with emissions from the operation of diesel trucks and equipment. However, according to industry analysts, many cement plants are set up to provide round-the-clock cement loading services to their customers. Since most customers rely on their own trucks and may not have the flexibility to defer deliveries, these plants need to load vehicles on a continuous basis as they arrive. In other cases, loading at night may create noise related problems with trucks traveling through residential neighborhoods. For these reasons, scheduling changes pertaining to bulk loading operations do not appear to hold promise as episodic control measures. However, industry analysts indicated that most facilities have some inventory of bagged product, and this may allow for short-term deferral of bagging operations on days with high air pollution concentrations. Nonetheless, there are indications that bagging operations account for only a small portion of a cement plant's overall emissions.

Summary: Scheduling Changes

Our discussions with industry analysts indicated there may be opportunities to implement short-term scheduling changes in certain ancillary activities without significant disruptions to kiln operations or facility production schedules. For example, some cement plants may be able to defer quarrying activities and/or operation of the finishing mill on days with high air pollution concentrations. Most plants already have the infrastructure to stockpile some quantity of raw materials or finished products. Thus, rescheduling these ancillary activities for limited time periods may be feasible, if given up to 24-hours advance notice.

iv. Combustion reoptimization

We also considered the following potential short-term combustion reoptimization techniques with regard to their ability to achieve incremental NOx emission reductions from the cement industry on days when high air pollution concentrations occur:

- Kiln operational control adjustments (such as controlling flame temperature or oxygen content).
- Cement kiln dust (CKD) recirculation and/or flue gas recirculation.

Combustion reoptimization techniques seem to hold little promise as an episodic control strategy for the cement sector. Most cement kilns, particularly in ozone nonattainment areas, already use sophisticated computerized control systems with combustion controls optimized for maximum kiln efficiency and product quality. And because cement kilns are heavily dependent on their steady-state performance for optimum operational efficiency, most analysts suggested there would be little room to reoptimize these systems on a short-term basis to obtain significant emission reduction benefits. Any short-term changes may actually reduce kiln efficiency and increase the emissions intensity of kiln operations.[53]

Summary: Combustion Reoptimization

Industry analysts believe that most kilns are currently optimized; any short-term modifications would likely reduce operational efficiency and could potentially increase emissions.

[53] One area that may need further evaluation is to determine whether there is a tradeoff potential in emission reduction goals through combustion reoptimization. For example, there appear to be ways to reoptimize kiln operations to further reduce NOx emissions for short intervals when high concentrations of ozone and PM2.5 occur at the cost of increasing CO emissions during those time periods.

d. Opportunity Assessment of Potential Episodic Control Options

Exhibit 17 summarizes the potential viability of the four primary options for further reducing emissions on days with high air pollution concentrations.

Exhibit 17: Opportunity Assessment – Cement

Option	Viability as Possible Episodic Control Measure
Fuel switching	**Unlikely** – Fuel switching on a large scale **Promising** – Small scale displacement of coal with other fuels in the kiln or precalciner (for NOx reductions)
Low cost retrofits and enhanced use of existing control equipment	**Promising** – SNCR for preheater/precalciner kilns (for NOx reductions) **Possible** – Micro-fine lime addition for facilities with spray cooling and conditioning towers (for SO_2 reductions)
Scheduling changes	**Promising** – For ancillary activities, such as deferring quarrying and/or running the finishing mill (to reduce direct emissions and electricity demand)
Combustion reoptimization	**Unlikely**

IV. Implications for Other Sectors

Although our primary focus in this study has been on three selected industry sectors–pulp and paper, iron and steel, and cement–some of the episodic control measures explored here may be applicable to other sectors as well. This section of the report assesses the implications of our findings for emission sources in other industry sectors.

a. Implications for Industrial Boilers

Episodic control measures applicable to industrial boilers in the pulp and paper sector, or iron and steel sector, may also be applicable to boilers in other manufacturing sectors. Exhibit 18 below shows the distribution of industrial boilers, by size, across major manufacturing sectors.

Exhibit 18: Industrial Boiler Inventory – Boiler Capacity (Number of Boiler Units in Parenthesis)

Boiler Capacity (MMBtu/ hr input)	Food	Pulp & Paper	Chemicals	Petroleum Refining	Metals	Other Manufacturing	Total
< 10	31,070 (6570)	4,105 (820)	28,660 (6,720)	1,255 (260)	7,505 (1,850)	29,710 (7,275)	**102,305** **(23,495)**
10-50	64,970 (3,070)	24,490 (1,080)	81,690 (3,370)	6,670 (260)	19,405 (920)	80,585 (3.680)	**277,810** **(12,380)**
50-100	37,885 (570)	36,665 (530)	64,970 (950)	18,390 (260)	22,585 (330)	62,630 (930)	**243,125** **(3,570)**
100-250	47,950 (330)	81,500 (540)	86,840 (590)	30,480 (200)	17,775 (110)	62,790 (440)	**327,335** **(2,210)**
>250	27,860 (70)	229,590 (490)	150,915 (350)	114,720 (220)	45,365 (120)	47,760 (110)	**616,210** **(1,360)**
Total	**209,735** **(10,610)**	**376,350** **(3,460)**	**413,075** **(11,980)**	**171,515** **(1,200)**	**112,635** **(3,330)**	**283,475** **(12,435)**	**1,566,785** **(43,015)**

Source: *ICF/EEA Boiler study for ORNL.*

As is evident from Exhibit 18, the chemical industry accounts for more than a quarter of the boilers used in all manufacturing sectors, in terms of total capacity, total number of units, and total number of large units (i.e., over 250 MMBtu/hr input). Use of industrial boilers in the food industry (consisting of 13 percent of total capacity, 25 percent of the total number of units, and 5 percent of the total number of large units) and petroleum refining industry (consisting of 11 percent of total capacity, 3 percent of the total number of units and 16 percent of the total number of large units), also make these industries particularly important candidates for the consideration of episodic control strategies where such strategies can help address air quality problems.

While there are sector-specific (and indeed, facility-specific) issues to analyze further, this section provides a general overview of a number of control measures that might have broad applicability to industrial boilers. Each of these potential measures is discussed in more detail in one or more of the preceding sections, including a more complete discussion of potential limitations and concerns.

i. SO_2 control measures

Our discussions with regulatory experts and industry analysts indicated there is a large population of industrial boilers that do not currently employ any SO_2 controls technologies. Boilers, including large boilers that pre-date the New Source Performance Standards for industrial boilers that came into effect in 1986, typically have no federal requirements for SO_2 control (although they may be subject to state-level requirements or consent decrees that require the use of control technology or low sulfur coal).

In situations where further SO_2 reductions are needed to address short-term air quality problems (e.g., violations of the 24-hour PM2.5 standard), but where installing a packed tower scrubber or other continuous SO_2 control device is not technically or economically feasible, facilities may be able to install a lime injection system to temporarily achieve additional SO_2 emission reductions on short notice as part of an episodic control strategy. For example, boilers that use a baghouse or ESP for PM control could intermittently inject lime powder into the duct that carries exhaust gases from the boiler to the baghouse or ESP to obtain further SO_2 reductions on a short-term basis. Boilers that do not have post-combustion SO_2 controls may also be able to reduce SO_2 emissions by switching to natural gas or a low-sulfur coal for limited periods of time, where those fuels are not currently being utilized.

In addition, industrial boilers that have been retrofitted with SO_2 control devices may have the ability to increase the control efficiencies of those devices, or to switch to a lower sulfur fuel, for short periods of time in certain situations.

ii. NOx control measures

SNCR systems may hold some promise as a short-term episodic control measure for reducing NOx emissions from industrial boilers in many industry sectors. SNCR technology has been in use for many years. However, in most sectors, its use has been limited to boilers that are subject to new source control requirements. While there are indications that some state and local air quality regulators may be considering the imposition of SNCR control requirements on existing industrial boilers in some industries, in situations where further emission reductions are needed to achieve air quality goals, the limiting factor to date has been the cost of installing and operating this technology.

According to industry analysts and technology vendors, the cost of purchasing and installing an SNCR system may be on the order of $1 million for a large industrial boiler. However, for most large boiler applications, the majority of the total annualized cost associated with an SNCR system may be for the reagent used (urea or aqueous ammonia). Therefore, the cost burden associated with installing and operating an SNCR system could be reduced significantly under an episodic control program. For example, in some situations it might be possible to reduce the total cost burden of an SNCR system by 50 percent or more if the system were installed and run at an intermediate control level on a continuous basis, and then ramped up to full capacity on days with high air pollution concentrations. The cost burden could be further reduced if the SNCR system were kept on standby and used only on days with high air pollution concentrations.

Another NOx control technology that might be used as part of an episodic control program is gas reburn. According to industry analysts and EPA experts, many industrial boilers have access to natural gas for use as a backup or starter fuel. For these boilers, limited capital expenditures would be required to install additional burner(s) and duct work to tie the burners to the gas supply. The majority of the cost would be for the additional natural gas needed to operate the technology. Because under an episodic control program the reburn technology would be used only on a limited number of days each year, the system may not be cost prohibitive even under the current scenario of high gas prices.

Finally, some industrial boilers may also have the ability to switch to fuels with lower nitrogen content or flame temperatures for short periods of time to achieve additional NOx emission reductions when high air pollution concentrations occur.

iii. PM control measures

Because of the history of regulatory requirements for PM abatement, the vast majority of industrial boilers appear to be controlled for primary PM. Most large boilers currently use baghouses, ESPs or venturi scrubbers for PM control purposes. While the industry analysts we spoke with were uncertain about how much opportunity there may be to increase the control efficiencies of these devices on a short-term basis, they felt there might be some situations in which this could be accomplished. For example, in some cases it may be possible to increase the voltage in an ESP in order to increase its PM control efficiency for short time periods. In addition, some boilers may be able to further reduce their PM emissions on a short-term basis by switching to a lower emitting fuel.

b. Implications for Other Industrial Sources

As with industrial boilers, some of the episodic control measures applicable to other units and processes within the three selected industries may be applicable to similar units or processes in other industries as well. Examples include fuel switching at furnaces and process heaters, installation of low capital cost retrofits, enhanced use of existing control equipment, and certain scheduling changes. Some sectors may also be able to provide additional, sector-specific opportunities for reducing emissions on an episodic basis. For example, in the course of our research we learned that a number of chemical facilities in the Gulf Coast region defer routine maintenance activities on high ozone days as part of local ozone action programs. Perhaps the most significant of the deferred maintenance activities relates to planned shutdowns. When shutting down a chemical plant for routine maintenance, facility operators typically need to flare off some of the VOCs from process vessels, and this can be a major short-term emission source.[54] Hence, the deferral of planned shutdowns at chemical facilities on high ozone days can avoid emission spikes at times when they would be most detrimental.

[54] A recent study of the Houston-Galveston area suggests that flaring is a major source of highly reactive VOCs from point sources in the area and, therefore, a potential major contributor to violations of the 8-hour ambient air quality standard for ozone. See Murphy, C.F. and D. T. Allen, "Hydrocarbon Emissions from Industrial Release Events in the Houston-Galveston Area and their Impact on Ozone Formation," *Atmospheric Environment*, 39, 3785-3798 (2005).

c. Implications for Electric Utilities

Several episodic control measures explored in this analysis involve the rescheduling of industrial processes that use large amounts of grid-supplied electricity (e.g., quarrying activities and finishing mill operations at cement plants, and melting operations at steel mini mills), to times when they are less likely to exacerbate air quality problems. Other industry sectors may have similar opportunities to temporarily halt, curtail or defer processes that use large amounts of grid-supplied electricity, as part of an episodic control program. These measures could be particularly useful on high electricity demand days when electric utilities may rely on very high emitting generating units in order to meet peak electricity demand. Reducing electricity demand from industrial sources on high electricity demand days, or shifting that demand from daytime to nighttime hours (when lower-emitting generating capacity is available and the resultant emissions may have less ozone or PM2.5 forming impact), could provide significant air quality benefits.

In addition to taking advantage of efforts by industrial sources to reschedule electricity-intensive operations, electric utilities may have the ability to employ other episodic control measures to reduce NOx, SO_2 and/or PM emissions on days when high air pollution concentrations occur. A number of such measures may be possible and warrant further research, including fuel switching strategies, dispatching strategies, installation of low capital cost retrofits, and enhanced use of existing control equipment.

3. Summary of Findings & Next Steps

As EPA, states, communities and other stakeholders consider the potential role that episodic control measures could play in attaining and maintaining air quality standards for ozone and PM2.5, one challenge will be to determine what measures can be viably and cost-effectively implemented by industrial sources on an episodic basis. This analysis identifies and preliminarily assesses a potential set of episodic control measures based on a review of literature and discussions with industry experts. In order to put some bounds on the research, we choose three industry sectors to serve as case studies for this analysis – pulp and paper, iron and steel, and cement. These sectors, however, are in no way an exhaustive list of sectors where episodic control measures may potentially be employed. Indeed, a number episodic control measures were identified in the course of this research that could have broad application to emission sources in other industries.

I. Findings

a. Episodic Control Measures Exist for the Three Selected Sectors

This study finds that there are a number of potential episodic control measures available for each of the three sectors analyzed. Further exploration of these measures is warranted to determine the extent to which they would provide net emission reductions, and to more fully assess the technical, cost, and operational impacts of the various measures on individual facilities.

- All three sectors possess some fuel switching capabilities and may be able to shift to lower emitting fuels to reduce NOx, SO_2, and/or PM on an intermittent basis for short periods of time. The manner and extent to which short-term fuel switching could be employed, however, varies from sector to sector. Since facilities typically select their fuels so as to minimize production costs and meet other operational objectives, switching to more expensive fuels on a continuous basis would be untenable for many facilities. However, because fuel switching under an episodic control program would only be invoked on a limited number of days each year, the total incremental costs may be within acceptable levels for many facilities.

- Installation of low capital cost retrofit technologies, such as selective non-catalytic reduction (SNCR) and gas reburn (for NOx control), and lime injection (for SO_2 control) appears to hold promise in the context of an episodic control program. Although the high O&M costs associated with these retrofit technologies (e.g., due to the significant consumption of reagent or natural gas) may make them cost prohibitive for use on a continuous basis at many facilities, they may be suitable for use at some facilities as an episodic control measure.

- Opportunities may exist to modify – and thereby enhance – the use of existing pollution control equipment on a temporary basis to control for additional pollutants (i.e., in addition to the main pollutant(s) these controls are intended for). For example, many industrial boilers and furnaces have venturi scrubbers. These scrubbers are generally installed as PM control devices but may also remove some SO_2 from the exhaust stream of the combustion unit. Some industry analysts and regulatory experts believe there may be an opportunity to enhance the SO_2 removal efficiency of venturi scrubbers in some situations by adding alkali reagent. This may be technically feasible and economical where a unit already has such a device and is able to obtain significant incremental SO_2 reductions on a short-term basis with the addition of the reagent.

- Opportunities may also exist to run existing pollution control devices more aggressively for short intervals to achieve incremental emission reductions. Some industry analysts thought that in some cases it might be possible to temporarily increase the control efficiency of a variety of NOx, SO_2, and PM control systems on days when high air pollution concentrations occur and where, for cost or other reasons, existing permit conditions do not require these control devices to be utilized at their maximum performance levels.

- While temporary shutdowns and curtailments that could disrupt core production processes were generally deemed inadvisable, there may be opportunities to curtail certain operations or rearrange production schedules on a short-term basis to move high emitting processes to times when they are less likely to exacerbate air quality problems. For example, because steel mini mill operation is generally batch in nature, some mini mills may be able to reschedule melting operations from daytime to nighttime hours to reduce VOC and NOx emissions, as well as electrical demand, during critical daylight hours when ozone formation is likely to occur. There may also be opportunities to defer certain ancillary activities at cement plants, such as quarrying activities and finishing mill operations, to reduce emissions as well as electrical demand on a short-term basis.

- Changing the dispatch of boilers at large pulp and paper mills with excess boiler capacity appears to be a feasible episodic control strategy in some instances.

- Additionally, there may also be other sector-specific episodic control opportunities, such as increasing the use of cogeneration units in the pulp and paper sector, which require further exploration.

- Episodic control measures related to combustion reoptimization techniques appeared less viable for the selected industry sectors. Most facilities in these sectors use sophisticated computer controlled equipment on highly inter-connected and synchronized production processes. Industry experts seemed reluctant to entertain the idea of altering the already optimized processes, as they might make the processes less efficient and/or more polluting.

b. Episodic Control Measures Also Exist for Other Industrial Sources

While this study has focused primarily on facilities in the pulp and paper, iron and steel, and cement manufacturing industries, our research and information gathering indicates that a wide variety of episodic control measures may be available for use by other industrial sources as well.

- A number of the episodic control measures that are applicable to industrial boilers in the pulp and paper sector, or the iron and steel sector, may also be broadly applicable to boilers in other industry sectors. For example, some industrial boilers in other industries may be able to install low capital cost retrofit technologies (such as SNCR or gas reburn for NOx control, or lime injection for SO_2 control), to reduce boiler emissions on a short-term basis. Other boilers may be able to temporarily reduce emissions by switching to a lower emitting fuel for limited periods of time. In addition, some boilers that have already been retrofitted with control devices may have the ability to increase the control efficiencies of those devices by modifying their operation (e.g., adding reagent to a venturi scrubber) or running them more aggressively for short time intervals (e.g., increasing voltage in an ESP).

- As with industrial boilers, a number of the episodic control measures that are applicable to other units and industrial processes in the three selected industries may be applicable to similar units or processes in other industries as well. Examples include fuel switching at furnaces and process heaters, installation of low capital cost retrofits, enhanced use of existing control equipment, and certain scheduling changes. Some sectors may also be able to provide additional, sector-specific opportunities for achieving emission reductions on an episodic basis.

- Several of the episodic control measures examined in this report involve the rescheduling of electricity-intensive industrial processes to times when they are less likely to exacerbate air quality problems. Other industry sectors may have similar opportunities to temporarily halt, curtail or defer electricity-intensive processes as part of an episodic control program. These measures could be especially helpful on high electricity demand days when electric utilities may rely on very high emitting generating units in order to meet peak-day demand for electricity. Reducing peak-day electricity consumption, or shifting that consumption from daytime to nighttime hours (when lower-emitting generating capacity is available and the resultant emissions may have less ozone or PM2.5 forming impact), could provide significant air quality benefits. Electric utilities may also have the ability to employ a variety of other episodic control measures to reduce NOx, SO_2 and/or PM emissions on days with high air pollution concentrations.

Industry analysts and regulatory experts emphasized that because of the inherent differences between facilities within a sector (as well as between sectors), generalized solutions for all facilities within a sector are unlikely to be effective. Episodic control measures need to be assessed on a plant-by-plant basis to determine their technical feasibility, practicality and cost-effectiveness.

II. Next Steps

This report is intended to provide a preliminary assessment of the wide array of episodic control measures that may be available to industrial sources. The potential measures identified in this report should be studied further as EPA, states, communities, and other stakeholders consider the potential role that episodic control measures could play in helping to meet ozone and PM2.5 air quality goals. A number of refinements to this analysis and additional research activities are recommended below to help EPA and other stakeholders more fully evaluate the potential contribution of episodic control measures.

- This analysis focuses primarily on three industry sectors – pulp and paper, iron and steel, and cement. While it also provides a cursory assessment of the potential applicability of episodic control measures to industrial sources outside of these sectors, further analysis with respect to other industry sectors is needed.

- To better assess the technical feasibility, emission reduction potential and cost of prospective episodic control measures, it will be necessary to conduct detailed engineering and cost analyses of specific measures. Because of the heterogeneity across facilities within a sector, as well as across sectors, these analyses will need to take into account site-specific and process-level emissions, as well as other source-specific considerations at individual facilities.

- In order to more fully assess the business and operational impacts of potential episodic control measures, it will be necessary to hold additional discussions with industry representatives and technical consultants.

- Because the ambient impact of episodic control measures is likely to be spatially differentiated, location-specific air quality modeling will be necessary to determine the actual contribution that short-term emission reductions from any particular industrial source or sector would make in solving local and/or regional air quality problems.

- In order to evaluate the potential utility of episodic control measures it will be necessary to review state-of-the-art practices pertaining to the prediction of ozone and PM2.5 episodes. The effectiveness of episodic control measures would in part depend on the degree of prior notice that can be provided to plant operators, which is in turn a function of the ability of regulatory agencies and/or other institutions to predict air pollution episodes. Certain strategies may be technologically feasible and cost-effective, but may not be good candidates to implement if adequate prior notice cannot be provided to the affected facilities.

- Another key step in the further exploration of episodic control strategies is to quantify the cost-effectiveness of these strategies on a dollar-per-ton of pollutant removed basis. Our discussions with industry analysts indicated that this is a major unknown, because episodic strategies for industrial sources have traditionally been overlooked in the air pollution control literature. It must be emphasized, however, that comparisons to cost-per-ton estimates based on continuous control programs would provide an erroneous picture, as the acceptable cost-effectiveness range for an episodic control program is likely to be substantially higher than the corresponding range for a continuous program. Thus, a better understanding of the range of cost-effectiveness values that could be appropriate given the benefits of an episodic control program needs to be carefully developed.

- A number of critical policy questions will also need to be addressed before episodic control measures can be systematically implemented. For example, how should these measures be integrated with continuous and seasonal control measures as part of an air quality management plan, and how might this vary based on the attainment status of an area? Should episodic control measures be mandated by regulation, negotiated as part of the permitting process, or pursued by individual facilities on a purely voluntary basis? What types of monitoring, record-keeping and reporting provisions should be required to ensure that episodic emission reductions are quantifiable and/or enforceable?

Appendix: Examples of Reactions by Industrial Sectors to the California Outages of 2001 and 2005

This Appendix discusses the challenges associated with unscheduled shutdowns in the pulp and paper, iron and steel, and petroleum refining industries due to the rolling blackouts that occurred in California in 2001 and 2005.

In large plants including pulp, paperboard, and paper mills, iron and steel mills, and petroleum refineries, the operations of their major processes and ancillary equipment are intertwined and synchronized. An *unscheduled* stoppage of a process or equipment could cost substantial revenue losses to a plant because it not only stops the operation of the process or equipment, but could also cause the breakdown of other units linked to the original unit. As such, the reliability of each process or piece of equipment has to be high. To maintain the reliability of equipment or entire production operations, industrial plants schedule regular maintenance of their equipment and processes. Some of these maintenance activities could require a stoppage of the entire plant's operation or the shutdown of particular units or groups of units in the plant. The stoppage schedule is designed as far in advance as possible to ensure worker safety, sufficient labor resources, minimal revenue loss, and equipment integrity upon the resumption of plant/equipment operations.

During the rolling blackouts in California in 2001 and again in 2005, manufacturing facilities were adamant that they should be informed well in advance and even asked for exemptions from blackouts. Industries were concerned that blackouts could be extremely costly (due to loss of revenue) and could also compromise worker safety. Petroleum refiners in California cited that refiners could not resume operations with just a simple flick of a switch. Petroleum refineries claimed that an hour-long shutdown could lead to a 2-3 day restart since tanks must be drained and heating units must be brought back to temperature. Also, refiners already try to follow a well-choreographed schedule of maintenance outages to ensure optimal operations in their plants, so that an unscheduled stoppage could put the maintenance schedule in disarray.

A possible unacceptable result of an unscheduled refinery shutdown or curtailment is the loss of gasoline/diesel fuel supply in the market, and as such could lead to an increase in gasoline/diesel fuel prices. Historically, refinery outages have generally been scheduled when markets are not tight (during non-summer season), and they therefore have had little or no measurable impact on monthly average prices. However, a government program that requires refiners to shutdown during the summer ozone season associated with peak gasoline demand, could result in a loss of gasoline/diesel supply in the market and a corresponding increase in fuel prices.

For the iron and steel industry, the implementation of a stoppage should differentiate between the integrated mill and the mini mill. An integrated steel mill is comparable to a petroleum refinery in the complexity of its processes and equipment. As such, an unplanned stoppage could also cause substantial costs apart from risks to worker safety. For instance, an unplanned shutdown of the blast furnace results not only in production losses but risks making the blast furnace unusable because of the iron solidifying in the blast furnace' air tuyeres. The cost to rebuild a blast furnace is estimated at approximately $100 million.

For mini mills, which use electric arc furnaces, it is possible to consider not a stoppage but a rescheduling of operations. During the California rolling blackouts, some mini mills with interruptible power contracts switched to firm contracts with their power suppliers because the power curtailments were too costly. Others rescheduled their melting operations to off-peak hours to enjoy the cheaper electricity rates during those times and still allow for the interruptible contract to continue. Note that a rescheduling to off-peak hours for the mini mills is a possibility because the operation is generally batch in nature.

Pulp, paper, and paperboard mills, like integrated steel mills and petroleum refiners, have a complex system of continuous operations that are well-synchronized. An unscheduled stoppage could be very expensive for the company. Paper mills have many large boilers and their start-ups require several hours. Several hours of lost production could be costly for a paper company. It could also cost the reduction of equipment reliability and lower product quality.

Paper mills, integrated steel mills, and refiners may also be large cogenerators and a number of them are Qualifying Facilities (QF). QFs are essential to the balancing of the power grid and so a shutdown of an industrial QF could cause demand-supply imbalance as well.

Another commonality among these industries is that they are capital-intensive so that maximizing the utilization of their assets is essential to their profitability. Also, these companies have substantial contracts with labor, their suppliers and their customers, and unmet obligations due to unscheduled stoppages of their operations could also have legal implications.