

**CCME**

Canadian Council  
of Ministers  
of the Environment

Le Conseil canadien  
des ministres  
de l'environnement



## **NATIONAL EMISSION GUIDELINE FOR CEMENT KILNS**

Initiative N306  
March 1998  
PN 1284

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The Canadian Council of Ministers of the Environment (CCME) is the major intergovernmental forum in Canada for discussion and joint action on environmental issues of major national, international and global concern. The 13 member governments work as partners in developing nationally consistent environmental standards, practices and legislation.

Canadian Council of Ministers of the Environment Secretariat  
123 Main Street, Suite 360  
Winnipeg, Manitoba R3C 1A3  
Tel.: (204) 948-2090  
Fax: (204) 948-2125

Prepared by the  
N306 Multistakeholders Working Group and Steering Committee

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For additional copies, please contact:  
CCME Documents  
c/o Manitoba Statutory Publications  
200 Vaughan Street  
Winnipeg, Manitoba R3C 1T5  
Tel.: (204) 945-4664  
Fax: (204) 945-7172





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# Glossary of Terms

Within the context of the Guideline, the meaning of certain terms is as described below.

<b>Calcination:</b>	The liberation of carbon dioxide gas from limestone material (calcium carbonate) through the addition of heat in the cement or lime kiln.
<b>Cement:</b>	A powdered product used in construction that is produced by combining, in a high-temperature kiln, materials containing calcium oxide, alumina, iron oxide and silica, to form a combination of calcium silicates.
<b>Cementitious Additives:</b>	Materials used as a substitute for clinker in the production of cement, including blast furnace slag, flyash, bottom ash or slag from power plants, and other limestone and ferrous by-products from various industries.
<b>Clinker:</b>	An intermediate product in cement manufacture, consisting primarily of calcium oxide pellets formed by high-temperature chemical transformation of the raw material feed; the pellets are subsequently cooled and ground into a fine powder.
<b>Clinker Cooler:</b>	A heat exchange device located at the clinker discharge end of the kiln to cool the clinker pellets and to provide preheated combustion air for the main kiln burner.
<b>Greenhouse Gases:</b>	A collection of gases, including carbon dioxide, methane and nitrous oxide, known to trap heat from the sun that has been reflected by the earth, thereby keeping the lower atmosphere warm.
<b>Low-NO<sub>x</sub> Burner:</b>	A burner designed to provide fuel and air staging and mixing to minimize peak flame temperatures and so reduce NO <sub>x</sub> emissions.
<b>Nitrogen Oxides (NO<sub>x</sub>):</b>	Refers collectively to nitric oxide (NO) and nitrogen dioxide (NO <sub>2</sub> ), expressed as a nitrogen dioxide equivalent.
<b>Rotary Cement Kiln:</b>	A large rotating horizontally sloped steel cylinder. Raw material consisting of a wet or dry limestone and clay mixture is fed into one end of the kiln, and is calcined by hot exhaust gases (CaCO <sub>3</sub> forms calcium oxide and CO <sub>2</sub> ). It is then partially melted, or sintered, into clinker by additional intense heat input.
<b>Preheater Kiln:</b>	A type of cement or lime kiln that has a multistage heat exchange tower at the feed end to preheat incoming raw material, to aid in calcination and to increase overall energy efficiency.
<b>Precalciner Kiln:</b>	A cement kiln incorporating an additional burner at the kiln inlet to provide calcination shortly after the preheater portion of the kiln. These are often shorter kilns with higher energy efficiency and production capacity.
<b>Staged Air Combustion:</b>	NO <sub>x</sub> control technology that uses more than one stage of combustion at the precalciner kiln inlet to form a reducing atmosphere followed by an oxidizing region.
<b>Selective Non-Catalytic Reduction:</b>	An emission control method utilizing injection of ammonia (NH <sub>3</sub> ), or ammonia-containing compounds, into the flue gas at an appropriate high temperature, to convert NO <sub>x</sub> into nitrogen and water vapour.
<b>Selective Catalytic Reduction:</b>	An emission control method whereby ammonia (NH <sub>3</sub> ) is injected into the flue gas upstream of a catalyst structure, at an appropriate moderate temperature, to convert NO <sub>x</sub> into nitrogen and water vapour.

# Abbreviations

<b>CCME</b>	Canadian Council of Ministers of the Environment
<b>CEM</b>	Continuous Emissions Monitoring
<b>kg</b>	kilogram
<b>NO<sub>x</sub></b>	nitrogen oxides
<b>SO<sub>2</sub></b>	sulphur dioxide
<b>CO</b>	carbon monoxide
<b>CO<sub>2</sub></b>	carbon dioxide
<b>CaO</b>	calcium oxide
<b>CaCO<sub>3</sub></b>	calcium carbonate
<b>NH<sub>3</sub></b>	ammonia
<b>VOCs</b>	volatile organic compounds



## Preface

In May 1991, the Canadian Council of Ministers of the Environment (CCME) issued Phase 1 of the Management Plan for Nitrogen Oxides (NO<sub>x</sub>) and Volatile Organic Compounds (VOCs). The aim of the Plan is consistent attainment of the Canadian maximum acceptable one-hour air quality objective for ozone of 82 parts per billion by the year 2005. This Guideline responds to initiative N306 of the Plan, one of a series of initiatives aimed at preventing future increases in emissions through emission limits for new sources. The Guideline addresses emission limits for new high-temperature kilns in the cement manufacturing industry, and makes recommendations for emission reductions from existing plants that are being modified or upgraded. While this Guideline establishes maximum broad national emission limits, it is acknowledged that federal, provincial or regional environmental authorities may impose more stringent limits in response to regional or local problems.

Principles considered to be important in developing the Guideline were pollution prevention, energy efficiency, cost effectiveness and a comprehensive approach to minimizing various emissions. While the Guideline NO<sub>x</sub> emission targets are aimed at new kilns, certain emission reduction strategies applied to modified existing kilns could also be beneficial. Where there are opportunities to improve the environmental performance and energy efficiency of kilns for which major modifications are planned, emission rates and control methods should be evaluated in close consultation with the appropriate regulatory authorities.

For the overall benefit of the environment, the Guideline encourages the use of substitutes for cement materials and for fossil fuels, where it can be demonstrated by the proponent that NO<sub>x</sub> emissions would not be increased. It also encourages the implementation of energy efficiency measures in cement production.

The Guideline was developed through a multistakeholder consultation process, by a working group consisting of representatives from the cement and lime industry, equipment manufacturers, environmental groups, and provincial, regional and federal governments. The contributions of all participants who assisted in the establishment of this Guideline are gratefully acknowledged.

Inquiries about the Guideline may be directed to:

Manager  
Oil, Gas and Energy Branch  
Air Pollution Prevention Directorate  
Environment Canada  
351 St. Joseph Blvd.  
Hull, Quebec K1A 0H3

Tel.: (819) 953-1120  
Fax: (819) 953-8903



## Introduction

The National Emission Guideline for Cement Kilns was developed to provide a consistent national basis for restricting emissions of nitrogen oxides ( $\text{NO}_x$ ) and other pollutants, while encouraging greater energy efficiency in the industry. A Technical Background Document was also prepared, through the consultation process, to describe the Canadian cement industries and available  $\text{NO}_x$  reduction methods. A summary of this document is presented in Appendix B to aid in the assessment of reduction strategies for new, existing and modified kilns.

In this National Emission Guideline,  $\text{NO}_x$  limits for cement kilns are expressed as weight of allowable emissions per unit of clinker production (kg/tonne). In determining allowable emission levels for cement kilns where major modifications are planned, consideration should be given to the offset of clinker production through the use of additives to clinker to produce cement, and the increase in energy efficiency available by the recovery of waste heat energy from cement kiln stack gases. The Guideline also addresses issues related to other common air pollutants, as well as monitoring of emissions.

### Cement Kilns

The cement industry is based on the conversion of a mixture of limestone ( $\text{CaCO}_3$ ) and clay, into clinker material consisting of compounds of calcium oxide ( $\text{CaO}$ ), by the addition of large quantities of heat in a coal- or gas-fired rotary kiln.  $\text{NO}_x$  formation results mainly from this high-temperature pyroprocessing stage which sinters the material into a cement clinker, as well as during initial limestone calcination. Carbon dioxide ( $\text{CO}_2$ ) is also liberated in this calcination process. Clinker production can take place in a wet-process long kiln with a slurry raw material feed, with a dry-process feed in a long kiln, or with a dry feed in more modern and efficient preheater and precalciner kilns.

Several methods of  $\text{NO}_x$  reduction were assessed during the development of the Guideline, although only some of these have been proven commercially. These include both combustion technologies which reduce or prevent emissions at their point of

generation, and post-combustion methods which reduce emissions already generated, as indicated below and explained in detail in the Technical Background Document:

- combustion operation modifications
- low- $\text{NO}_x$  burners
- staged air combustion
- selective non-catalytic reduction
- selective catalytic reduction.

Process optimization through combustion modifications is one of the first options to be considered for improving process efficiency and for reducing emissions. The use of low- $\text{NO}_x$  burners is being studied internationally, with a wide variety of results on installed systems. These burners usually require an indirect-fired system, whereby most combustion air is provided independently of the burner. Selective non-catalytic reduction using injection of ammonia compounds is also being investigated as a feasible post-combustion technology. There has been very limited experience on flue gas control methods such as selective catalytic reduction, or on technologies such as staged air combustion for precalciner kilns. Experience has shown that  $\text{NO}_x$  emissions from coal-burning kilns are often lower than from natural gas-burning kilns.

This Guideline recognizes that optimized and energy-efficient kiln processes, such as preheater and precalciner kilns with modern process and particulate controls, are the most effective means of minimizing the majority of emissions from cement kilns. These methods focus on cost-effective pollution prevention measures, and also address a variety of emissions including greenhouse gases.

$\text{NO}_x$  emissions can also be minimized through reductions in the clinker/cement ratio, and tests with waste-derived fuels have in some cases shown a positive impact on reducing emissions. Regulatory authorities should consider the overall environmental impacts of incorporating flyash or slag mixed into the finished cement product to reduce the need for clinker, and of using substitute



waste fuels such as solvents, tires and landfill gases to supplement traditional fuels. For technical guidance on operating and performance standards, reference is made to a separate CCME publication entitled *National Guidelines for the Use of Hazardous and Non-Hazardous Wastes as Supplementary Fuels in Cement Kilns*.

## National Emission Guideline for Cement Kilns

### Applicability

The emission limits of this Guideline apply to all large new cement kilns with a permitted capacity greater than 1 500 tonnes per day, which receive final regulatory approval for construction after January 1, 1998. The Applicability clauses are subject to alteration by the appropriate regional or provincial regulatory authority.

For an existing large cement kiln, the Guideline limits stated below shall apply when a modification results in a 25-percent increase in permitted kiln capacity. Modifications that result in capacity increases below this level should be allowed only once, to avoid the use of multiple kiln upgrades to circumvent the intent of the Guideline.

For modifications associated with one-time lesser increases in permitted capacity, a program to improve performance should take advantage of cost-effective technologies to achieve feasible emission reductions. The resulting emission levels from these modified kilns do not necessarily have to meet limits stated for new kilns. Where there are opportunities to improve environmental performance and energy efficiency on kilns for which major modifications are planned, emission rates and control methods should be evaluated in close consultation with the appropriate regulatory authorities.

Approval for special dispensation may be sought from the appropriate regulatory authority in developing appropriate emission guidelines for the following cases:

- for new small cement kilns with capacities of less than 1 500 tonnes per day, where it can be

shown that the installation of a facility such as a long dry kiln is justifiable,

- where it can be demonstrated that the kiln is occasionally operated under unique circumstances.

### Emissions of Nitrogen Oxides

The emissions from new natural gas or coal-fired cement kilns should not exceed 2.3 kg of NO<sub>x</sub> per tonne of clinker production, based on a monthly average time period. Shorter time averaging periods with a somewhat higher emission rate, to reflect unsteady emissions, could be chosen by permitting authorities for site-specific reasons, if deemed appropriate.

For the use of other fuels such as oil or petroleum coke on a temporary basis, or for the use of alternative fuel mixes including landfill gas on an ongoing basis, approval should be sought from the appropriate regulatory authority.

Where the proponent can demonstrate that clinker production can be offset by the addition of cementitious additives such as flyash or slag, a higher NO<sub>x</sub> limit (kg/tonne clinker) could be considered by regulatory authorities. This limit would be based on the portion of clinker produced from primary raw materials, excluding any cementitious additives such as flyash or slag. Such an allowance would serve to increase the kg/tonne of clinker emission level for the kiln, and to recognize a reduction in overall net emissions for a given amount of cement produced. The use of such additives should not result in an increase in total NO<sub>x</sub> emissions (at full capacity) from the kiln where the allowance is used.

A similar approach could be considered if waste heat from the stack exhaust or clinker cooler was shown to be used for any other heating or industrial processes not normally associated with kiln operation. The emission allowance would correspond to the emissions savings that would result from reduced fuel combustion for that heating or process application.



## **Emissions of Other Pollutants**

When considering the installation of process modifications to reduce emissions of  $\text{NO}_x$ , caution should be exercised to minimize the adverse environmental impacts of other pollutants, while maintaining acceptable clinker quality. New kiln systems should be designed, and raw materials selected, to minimize sulphur dioxide ( $\text{SO}_2$ ) and carbon monoxide (CO) emissions while remaining in compliance with  $\text{NO}_x$  emission guidelines. These emissions should be assessed on a site-specific basis as determined by the appropriate regulatory authority.

### ***Particulates***

The fine particulate dust contained in the kiln gases exiting from the main stack or from the clinker cooling system can be controlled by the use of equipment such as an electrostatic precipitator or a fabric filter baghouse. Particulate emissions in the exhaust gases for new kilns should not exceed 0.2 kg per tonne of clinker from the stack, and 0.1 kg per tonne from the clinker cooling system.

### ***Sulphur Dioxide***

Sulphur dioxide generated from the raw material feed into the process, and from the sulphur content in the fuel, is usually captured to a large extent in the preheater tower and in the raw clinker grinding mill. Since raw material composition is very site-specific, and  $\text{SO}_2$  emissions are sometimes inversely related to  $\text{NO}_x$  emissions, new kiln systems should be designed to minimize  $\text{SO}_2$  concentrations in the flue gas, while staying in compliance with  $\text{NO}_x$  emission guidelines.

### ***Carbon Monoxide***

The presence of carbon monoxide in the kiln exit gas or in the downstream particulate control systems should be monitored to prevent unsafe conditions, and to allow the fuel supply to the kiln to be curtailed should CO concentrations rise higher than equipment specifications permit. Kiln systems should be designed to minimize CO concentrations while staying in compliance with  $\text{NO}_x$  emission guidelines.

## **Measurement and Monitoring**

In order to confirm that the plant is operated in a manner consistent with this Guideline, all new cement kilns should measure  $\text{NO}_x$  and  $\text{SO}_2$  emissions using a continuous emissions monitoring (CEM) system. If the measurement system used for process control at the kiln exit is to be used for emissions reporting, the proponent should demonstrate a method that shows these emissions to be representative of those exiting the stack.

In all cases, measurement, monitoring and reporting requirements are subject to approval by the appropriate regulatory authority. Measurement methods should be generally consistent with those developed and published for this purpose by Environment Canada.

On existing kilns which are to undergo major modifications, measurement should be done with a CEM system, or by a method of comparable effectiveness to continuous monitoring as determined by the appropriate regulatory authority. Such methods could include mass balance calculations for  $\text{SO}_2$  or predictive/parametric monitoring. These methods could be supplemented by periodic source sampling and analysis.

Plants that intend to seek emission allowances for cementitious additives or waste heat utilization should provide adequate mass balance and energy calculations.

# Appendix A

## Working Group Members

### Provincial and Regional Governments

Martin Lecours	Ministère de l'Environnement et de la Faune du Québec
Hanna Corinthios	Ontario Ministry of the Environment
Chow-Seng Liu	Alberta Environmental Protection
Kamal Bhattacharyya	Greater Vancouver Regional District

### Industry

Allan Moore	Tilbury Cement
Peter Darbyshire	Continental Lime (Canadian Lime Institute)
Murray Smith <sup>(1)</sup>	Union Gas (Canadian Gas Association)
Charles Coles <sup>(2)</sup>	St. Lawrence Cement (Canadian Portland Cement Association)
Jacques Denizeau	Lafarge Canada
Steve Prahacs <sup>(3)</sup>	Pulp and Paper Research Institute of Canada
Richard Plante	Graybec Lime
Paul Arsenault <sup>(4)</sup>	Pillard Combustion

### Environmental Non-Government Organization

Bruce Walker <sup>(5)</sup>	STOP
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### Federal Government

Horace Whaley	CANMET Energy Research Laboratory
Hugh Dibbs	Environment Canada
Manfred Klein	Environment Canada

- (1) Replaces Ron Brintnell, Union Gas
- (2) Replaces Michael Nisbet, Lafarge Canada
- (3) Replaces Iver Simonsen, PAPRICAN
- (4) Replaces Gilles Uguen, Pillard
- (5) Replaces Ellen Schwartzel, Pollution Probe



## Appendix B

# Technical Background Document Assessment of NO<sub>x</sub> Emission Control Technologies for Cement and Lime Kilns

Radian Canada Inc., April 1995

## Executive Summary

As part of the Canadian Council of Ministers of the Environment (CCME), Environment Canada is addressing the issue of NO<sub>x</sub> emissions, together with other air pollution matters, by coordinating a multi-stakeholder consultation process to develop national emission guidelines for major stationary combustion sources. Initiative N306 of the CCME Plan addresses the cement and lime manufacturing industries, and will result in the publication of a nitrogen oxides (NO<sub>x</sub>) emission guideline for new and modified plants.

This report by Radian Canada Inc. is intended to provide Environment Canada and members of the N306 Working Group on Cement and Lime Kilns with a review and evaluation of the state of the art in NO<sub>x</sub> emission control technology as applicable to cement and lime kilns. The report is based on information available from the two industries concerned; regulatory agencies in Canada, the United States and Europe; and experience within Radian itself of direct investigations of NO<sub>x</sub> control systems. This assessment will be used by CCME in making recommendations for national emission guidelines. It may also become a part of a CCME background publication for the application of remedial measures for existing facilities.

The report provides background information on the Canadian cement and lime industries, giving both an economic and production technologies overview. It presents the available NO<sub>x</sub> emission data from both Canadian and other sources, and gives a worldwide view of NO<sub>x</sub> guidelines and targets for the two respective industries. The mainstay of the

report is a detailed review of existing NO<sub>x</sub> control technologies: a technical description of them, and an assessment of their applicability to cement and lime kilns, from both an engineering and economic perspective. NO<sub>x</sub> emission monitoring is considered as well. Conclusions and recommendations identify possible approaches to be taken in considering applicable control technologies and developing national emission guidelines for the new and modified kiln operations.

As there are significant differences between the two industries, as well as differences in the amount of relevant information available on the subject of NO<sub>x</sub> emissions and their control, the cement and lime industries are addressed separately in this report.

### **Cement Kilns**

During the past 20 years, considerable knowledge of NO<sub>x</sub> generation, emission and control has been obtained from research into the combustion of fossil fuels and from combustion in utility boilers and industrial processes. Although many researchers have tried, these data cannot be extrapolated to the Portland cement manufacturing process. There is a limited amount of published data regarding NO<sub>x</sub> emissions from cement kilns. However, even on the basis of this limited information, there is an indication of a strong dependence of the amount of NO<sub>x</sub> emissions generated and the type of the kiln and the fuel used (Table A1).



**Table A1. NO<sub>x</sub> Emissions From Cement Kilns\***

Fuel	Wet	Long Dry	Preheater	Precalciner
Natural Gas	9.0	7.0 - 9.5	5.65	1.7 - 3.0
Oil	nda	3.3 - 4.6	nda	nda
Coal	1.45 - 4.33	2.4 - 4.6	1.5 - 2.85	1.35 - 1.95

\* kg NO<sub>2</sub> / tonne of clinker; nda = no data available

Modern preheater and precalciner kilns usually generate lower NO<sub>x</sub> emissions than older, less energy efficient wet and long dry kilns, when all are fired using the same type of fuel. At the same time, long dry kilns do not necessarily have lower NO<sub>x</sub> emissions than wet kilns.

Using the same type of kiln process technology, coal generates substantially less NO<sub>x</sub> than both natural gas and bunker oil, strongly confirming that in cement kilns due to their high combustion temperature regimes (1630–1900°C vs. 1150°C for utility boilers), *thermal* NO<sub>x</sub> is the dominant factor, and *fuel* NO<sub>x</sub> only a secondary one. In terms of NO<sub>x</sub> generation, the dominance of coal as a fuel as opposed to natural gas or oil is a major difference between cement kilns and most of the other stationary NO<sub>x</sub> emission sources such as utility and industrial boilers.

There is a strong indication that use of some waste derived fuels (WDF) has a beneficial effect on reducing NO<sub>x</sub> emissions. This approach could be useful provided there are no negative effects on other emissions, clinker quality and kiln operation/maintenance.

Cement kiln emission limits and regulations enacted or proposed in different countries indicate not only concern about NO<sub>x</sub> emissions and their effects on the environment, but in some cases also a certain misunderstanding with respect to what is practically and economically achievable. The current limits vary widely, depending on the country or the district where the cement plant is situated. There are also difficulties in comparing various data and limits due

to the different units in which emissions are given. Most European data is reported either in *ppm<sub>v</sub>* or in *mg of NO<sub>x</sub> per Nm<sup>3</sup>*. Measurements can also be reported either *dry* or *wet*, as well as at various O<sub>2</sub> levels. Alternately, and this is the usual case in North America, especially when it comes to the units used by the regulatory bodies, mass measurements of emissions per unit of finished product, specifically *kg NO<sub>x</sub>/tonne*, are preferred. The European Community, where the cement industry has been modernized faster than in North America, and most of the kilns are either of the preheater or precalciner coal-fired type, appears to be heading to a two-tier regulatory system, in which the majority of countries will have a standard in the 2.75–3.6 kg NO<sub>x</sub>/tonne of clinker range, and environmental leaders like Germany and Switzerland will aim at 1.3–2.0 kg NO<sub>x</sub>/tonne of clinker. Japan also appears to have a low NO<sub>x</sub> emission standard.

A number of NO<sub>x</sub> reduction technologies have been considered for application in cement kilns. These include both *combustion* and *post-combustion* technologies, many of which have already been tested, commercially used and proven in other industries. Combustion NO<sub>x</sub> control technologies are dependent on the NO<sub>x</sub> formation mechanisms, and they attempt to control and reduce NO<sub>x</sub> emissions at the point of their generation; whereas post-combustion technologies are independent of the manner in which NO<sub>x</sub> is created, and act on already generated NO<sub>x</sub>.

It has to be stressed that not all NO<sub>x</sub> control technologies known and used in other industrial and utility applications are applicable to cement kilns.



Even if a given NO<sub>x</sub> control technology is proven to be highly successful in, for example, industrial boilers, it does not mean that it will work in the dusty, high-temperature atmosphere of the cement kiln. A specific kiln processing technology, kiln processing conditions (especially temperature regime and excess/lack of oxygen), finished product specifications, and the relationship with the other emissions, determine the feasibility and applicability of a specific NO<sub>x</sub> control technology to a specific cement operation.

NO<sub>x</sub> control technologies considered for application in cement kilns and discussed in some detail in the report include:

- combustion operation modifications (COM),
- low NO<sub>x</sub> burners (LNB),
- staged air combustion (SAC),
- selective non-catalytic reduction (SNCR),
- selective catalytic reduction (SCR).

From an extensive survey of the current state of the art, the study has drawn the following specific conclusions concerning these NO<sub>x</sub> control technologies and their general applicability to the cement industry.

Overall, the application of NO<sub>x</sub> control technologies is kiln- and site-specific. Success of a particular NO<sub>x</sub> reduction technology on a particular kiln does not guarantee similar results in an apparently “similar” cement kiln elsewhere.

In the published literature, there seems to be a consensus that of the various NO<sub>x</sub> control technologies, the combustion operation modifications (COM), low NO<sub>x</sub> burners (LNB), staged air combustion (SAC) and selective non-catalytic reduction (SNCR) approaches appear feasible for cement kiln applications. The last two technologies (SAC and SNCR), however, have not as yet been reduced to proven industrial practice.

The NO<sub>x</sub> reduction potential of the control technologies is 15–30% for COM, 15–30% for LNB, 20–50% for SAC, and 40–70% for SNCR. (If two

technologies are implemented at the same time, the overall reduction efficiency does not equal their sum.) Technical feasibility, in descending order, is COM > LNB > SAC > SNCR; and relative costs and cost effectiveness, in ascending order, range COM < LNB ≈ SAC < SNCR.

Any COM action leading to a reduced fuel consumption and to an improved process stability will contribute to minimizing NO<sub>x</sub> emissions (potential 15–30% NO<sub>x</sub> reduction). Kiln operating parameters — such as the burning zone temperature, the amount of excess air and flame shape — are some of the factors greatly affecting the level of NO<sub>x</sub> emissions. All actions taken to improve fuel efficiency, process stability and the reduction of the burning zone temperatures should have a positive effect on product quality. On the other hand, actions taken to alter the combustion and to enhance local reducing conditions in the burning zone may affect the clinker quality and kiln operation.

Among the available NO<sub>x</sub> control technologies, LNBs appear to be considered and tried most, at least for applications in indirectly coal-fired long dry, preheater and precalciner kilns (potential 15–30% NO<sub>x</sub> reductions). There are a number of commercial vendors of LNBs. Their performance is site specific, and at a number of locations they do not perform up to full expectations. Longer term experience in the cement industry with LNBs is mixed, and there are still a number of questions regarding their efficiency in cement kilns. The capital costs of LNBs are relatively low; however, the capital investment can be significantly higher, if a simultaneous conversion from a *direct coal-fired* to *indirect coal-fired* system is required. LNB operation is site specific and the clinker quality and kiln operation can be affected; CO and THC may increase.

SAC is applicable primarily to *precalciner* and *preheater* kilns (potential 20–50% NO<sub>x</sub> reductions), although it can be adopted, to some extent, in mid-kiln firing of secondary fuels in long kilns as well. There has been only one full-scale cement plant industrial installation of SAC reporting on the experience. The findings, covering SAC installed



in 1987/88, confirmed a reduction in  $\text{NO}_x$  emissions; however, simultaneous and significant increases in CO and  $\text{SO}_2$  levels were experienced. Although under ideal circumstances, SAC could be fitted onto existing preheaters/precalciners, in reality these  $\text{NO}_x$  control technologies can be incorporated only during the design stages for new installations. SAC capital costs could be limited to those of additional burners plus the cost of any incremental, site-specific additional modifications. However, major conversion of an existing wet or long dry operation to a modern preheater/precalciner kiln incorporating SAC could be in the multi-million dollar range. It is not expected that SAC would affect clinker quality; however, CO,  $\text{SO}_2$  and THC emissions may increase. Due to the small number of existing trials and installations, further testing of SAC is needed; nevertheless, this technology seems to hold some promise for cost-effective  $\text{NO}_x$  control in the cement industry.

SNCR is also applicable only to modern preheater and precalciner kilns (potential 40–70%  $\text{NO}_x$  reductions). Although a few short-term trials both in the U.S. and Europe using either ammonia or urea injection have been reported recently, this technology is not fully proven as yet. There has been no full-scale SNCR installation in the cement industry. Implementation of SNCR will result in additional operational costs due to reagent costs. SNCR is not expected to affect clinker quality, as it is located downstream of the clinkering zone. A potential for  $\text{NH}_3$ , CO and  $\text{PM}_{10}$  emissions exists, as well as the formation of a plume containing ammonium salts. Although SNCR seems to be a rather promising  $\text{NO}_x$  control technology for preheater and precalciner cement kiln applications, due to a limited number of existing trials and no full-scale installations, as well as considerable capital and operational costs involved, further testing and proof of its long-term feasibility is needed.

SCR may provide high (70–90%)  $\text{NO}_x$  reduction for all kilns at very high capital and operational materials/labour costs, but its technical feasibility is still uncertain. There has been no trial of SCR on a cement kiln.

As far as a potential target for  $\text{NO}_x$  emissions from new or modified cement kilns is concerned, it would appear that for modern preheater/precalciner coal-fired kilns (these constitute the majority of the kilns built in Canada and elsewhere in the world over the last 15–20 years, and would also be, with high probability, built in the future), a range of 2.0–2.5 kg  $\text{NO}_x$ /tonne of clinker could be considered.

The main features of the  $\text{NO}_x$  control technologies as applied to cement kilns are summarized in Table A2.

### ***Lime Kilns***

There is virtually no information about  $\text{NO}_x$  emissions from lime kilns available in the literature. This is perhaps due to the fact that the lime industry is much smaller than the cement industry, that its kilns operate at lower temperatures than cement kilns (~1200°C vs. 1500°C), thus possibly generating lower  $\text{NO}_x$  emissions, and that the lime industry, unlike the cement industry does not monitor  $\text{NO}_x$  levels for process control. The EPA AP-42 emission factors are 1.4–1.7 kg of  $\text{NO}_x$ /tonne of lime for rotary kilns, depending on the type of fuel, while the limited data reported by the Canadian lime manufacturers range from 0.5 to 3.5 kg  $\text{NO}_x$ /tonne of lime. There is an indication that shaft and Calcimatic kilns generate less  $\text{NO}_x$  than rotary kilns.

Due to some similarities between the cement and lime processes, while at the same time recognizing the differences between the two materials and processes, it would appear that those control technologies identified as the most promising for cement kilns would be, with necessary modifications, applicable to the rotary lime kilns, should the need arise, i.e.:

- combustion operation modifications (COM),
- low  $\text{NO}_x$  burners (LNB),
- staged air combustion (SAC),
- selective non-catalytic reduction (SNCR).



**Table A2. Comparison of NO<sub>x</sub> Control Technologies for Cement Kilns**

Control Technology	Technical Feasibility	Potential NO <sub>x</sub> Reduction <sup>x</sup>	Annualized Cost Range 000\$/yr	Cost Effectiveness \$/t of NO removed <sup>x</sup>	Effect on Clinker Quality	Effect on other Emissions
COM	High (all types of kilns)	15–30%	-	-	may be either positive or adverse	SO <sub>x</sub> , CO, THC may increase
LNB indirect-fired* direct-fired** kilns	High (all types of kilns)	15–30%	110–160* 370–590**	340–570* 1,280–2,050**	may vary with installation; type of fuel; may be detrimental	may vary with installation, CO, THC may increase
SAC	High (precalciner, preheater <sup>†</sup> and long <sup>†</sup> kilns)	20–50%	120–160 <sup>†</sup> 180–220 <sup>†</sup>	250–400 <sup>†</sup> 660–940 <sup>†</sup>	none	CO, THC may increase
SNCR	Medium (precalciner kilns)	40–70%	610–1,250	1,220–1,690	none	potential for NH <sub>3</sub> , PM <sub>10</sub> emissions
SCR	Low (all types of kilns)	70–90%	3,510–10,050	4,840–7,500	none	potential for NH <sub>3</sub> , PM <sub>10</sub> emissions; SO <sub>3</sub> may increase

However, it seems that none of these control technologies have been tried as yet on rotary lime kilns, and that the industry at this time questions their applicability. It would appear that at this stage there is no need to consider specific NO<sub>x</sub> control steps for the shaft and Calcimatic kilns due to their inherently low NO<sub>x</sub> generation, but this should still be confirmed through independent measurements.

## Recommendations

The following recommendations are made with respect to the application of NO<sub>x</sub> control technologies to cement and lime kilns:

### Cement Kilns

- A survey should be conducted to generate a database for the total emissions and emissions per unit of production of NO<sub>x</sub> in Canadian cement kilns per type of kiln and type fuel used.
- Full advantage of COMs and process optimization should be taken for all cement kilns before any other NO<sub>x</sub> control technology is considered.
- Further testing of LNBs is required by the cement industry to assess their long-term ability to produce consistent low NO<sub>x</sub> emissions and high quality clinker at the same time, without adversely affecting other emissions.

- While SAC and SNCR hold promise for significant cost-effective NO<sub>x</sub> control, the full environmental and process impacts still need to be further ascertained, due to the small number of trials and existing installations.
- The effect of NO<sub>x</sub> emission regulations on other pollutants (SO<sub>2</sub>, CO, VOC, particulates) should be carefully investigated, and their negative impact weighted.
- As older wet and long dry kilns approach the end of their life-cycle, they could be converted to preheater/precalciner kilns, if market conditions and technical and economical feasibilities support this conversion.
- Use of waste derived fuels (WDF), known to generally reduce NO<sub>x</sub> emissions, could be considered, provided that there are no adverse environmental impacts and negative effects on clinker quality or kiln operation/maintenance.
- Continuous emission monitoring systems (CEMs), located either at the stack or at the kiln exit, might be necessary to meet the monitoring provisions on all large kilns. Alternate systems, such as PEMs, could be used on smaller kilns.

Based on information from the most recent long dry or preheater/precalciner installations that burn either coal or gas and for which there were reliable NO<sub>x</sub> emissions data available, representatives of the cement industry prepared a first draft of guidelines for the N306 Cement and Lime Working Group's consideration. For new or significantly modified cement kilns, based on the best demonstrated NO<sub>x</sub> control technologies, the industry is proposing two sets of guidelines: one for short-term periods based on daily averages plus two standard deviations (for compliance 95% of the time); the other based on longer term averages, yearly or monthly.

Proposal for the guidelines, as presented by the industry, are given in Tables A3 and A4.

**Table A3. Cement Kilns NO<sub>x</sub> Emission Guidelines, Daily Averages  
(kg NO<sub>2</sub>/tonne of Clinker)**

	Long Dry Kiln	Preheater/ Precalciner Kiln
Gas-fired kiln	$5.0 + 2 \times 0.35 = 5.7$	$2.1 + 2 \times 0.2 = 2.5$
Coke/Coal-fired kiln	$3.0 + 2 \times 0.5 = 4.0$	$2.1 + 2 \times 0.2 = 2.5$

**Table A4. Cement Kilns NO<sub>x</sub> Emission Guidelines, Annual Basis  
(kg NO<sub>2</sub>/tonne of Clinker)**

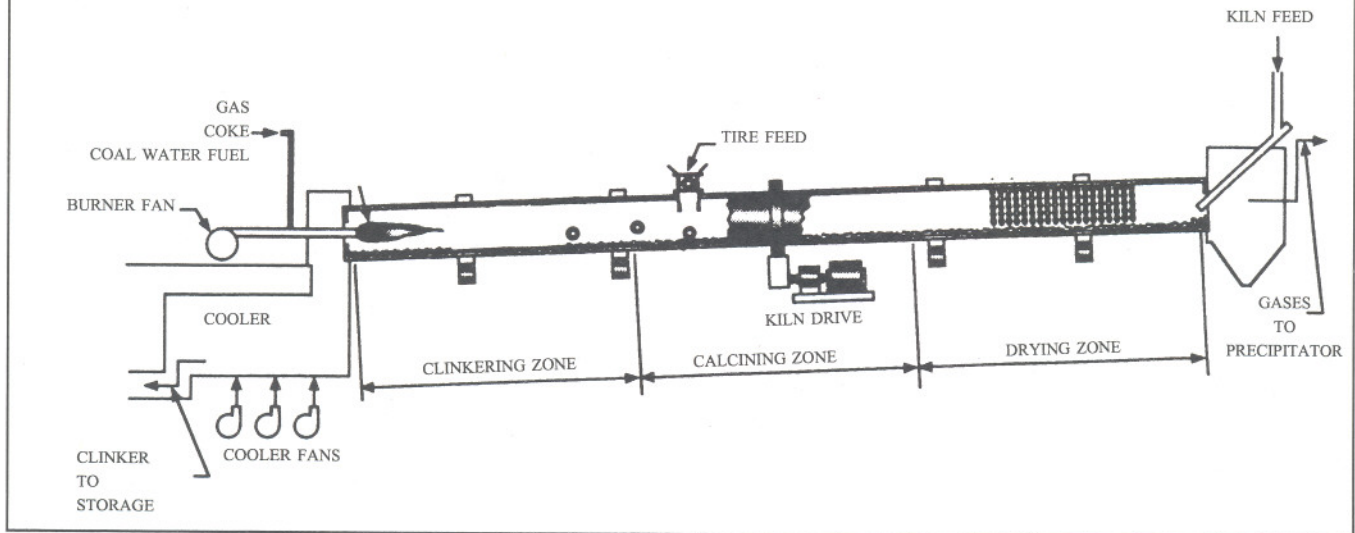
	Long Dry Kiln	Preheater/ Precalciner Kiln
Gas-fired kiln	5.0	2.1
Coke/Coal-fired kiln	3.0	2.1



### ***Lime Kilns***

- There is a need for NO<sub>x</sub> emissions testing and development of a Canadian database relating NO<sub>x</sub> generation to the type of lime kiln and the type of fuel used.
- Only once such a database is established, could firm targets be considered for NO<sub>x</sub> reduction. In the absence of such information, the range 1.5–2.0 kg NO<sub>x</sub>/tonne of lime is suggested as a preliminary target for modern lime rotary kilns with preheaters at this time.

## Long Wet and Dry Cement Kiln Process



*Courtesy of Canadian Portland Cement Association*

## Preheater and Precalciner Kiln Process

