AN ASSESSMENT OF THE USE OF TIRES AS AN ALTERNATIVE FUEL

Final Report

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Note on Concentration Measurements

The concentration of gaseous pollutants is usually expressed as parts per million on a volume basis (ppmv). 1 ppmv ≡ 10^{-4} vol %. Gaseous pollutant concentrations can also be expressed in terms of mass per unit volume of stack (or flue) gas. It is normal to correct the volume to some standard condition and also correct to standard oxygen content. When this is done it is termed a reference cubic meter (Rm^3) and refers to a volume of gas at 25°C (298 K) and 1 atmosphere (101.3 kPa) with concentrations corrected to 11% oxygen and zero percent moisture (dry). Thus, gaseous pollutant concentrations can also be expressed as milligrams (10^{-3}) per reference cubic meter (mg/Rm^3).

Ambient gaseous pollutant concentrations are either expressed as ppmv or milligrams per cubic meter of air (mg/m^3) or micrograms (10^{-6} g) per cubic meter of air ($\mu g/m^3$). The air volume is normally referenced to a temperature of 25°C (298 K) and 1 atmosphere (101.3 kPa).

Dioxin and Furan emissions are reported in picograms (10^{-12} g) of International Toxic Equivalent (pg I-TEQ). This method accounts for the differences among the various compounds by estimating toxicity of the individual dioxin compounds using a Toxic Equivalency Factor (TEF) described in Appendix A. The concentrations of gas-phase emissions of Dioxins and Furans are reported as pg I-TEQ/Rm^3.

The concentration of dioxins and furans measured in solids is expressed as the mass of toxic equivalent per unit mass of solid. Concentrations are usually expressed as nanograms (10^{-9} g) of International Toxic Equivalent per kilogram (10^3 g) of solid (ng I-TEQ/kg).

Note on Emission Rates

Emission rates of major gaseous pollutants are usually expressed in grams per second (g/s), whereas emission rates of volatile organic compounds (VOC), chlorobenzenes and cholophenols (CB and CP) are usually expressed in micrograms per second (μg/s). Emission rates of metals are usually expressed in milligrams per second (mg/s). Emission rates of dioxins and furans are usually expressed in picograms International Toxic Equivalent per second (pg I-TEQ)/s.

Note on Emission Factors

Emission factors are based on mass of pollutant per unit mass of product, which for the cement industry is per tonne (t) of clinker, thus emission factors are measured in kg/t.

Note on Tolerable Daily Intake

A tolerable daily intake (TDI) is an estimate of the amount of a substance present in air, food or drinking water that can be taken in by the body on a daily basis for an entire lifetime without incurring any appreciable health risk. A TDI for a particular substance is calculated from laboratory toxicity data in conjunction with an uncertainty factor. A TDI is measured in terms of a mass of the substance per unit mass of body weight per day. For metals and many other chemical substances it is usually expressed in $\mu g/(day \cdot kg_{bw})$. For dioxins and furans it is expressed as pg I-TEQ/$(day \cdot kg_{bw})$.

Executive Summary

The management of scrap tires in both Canada and the United States has been reviewed. On a weight basis the use of scrap tires in the US as tire derived fuel (TDF) has been steadily increasing since 1990 and in 2006 accounted for 59.3% of all tires. In Canada in 2005 20% of all scrap tires were used as TDF. Most TDF in Canada is used as a supplemental fuel in cement kilns where whole tires can be directly injected into the kiln.

We have also identified potential industrial applications within Nova Scotia (other than cement kilns) which could possibly utilize TDF. There is potential for use of TDF in the pulp and paper industry. Likewise, there may be potential for the use of TDF in the Point Aconi generating station.

Literature pertaining to the end use of used tires has been reviewed. Life cycle analyses (LCA) have shown that cryogenic pulverization is the most harmful to the environment, followed by mechanical pulverization. A number of LCA have shown that using tires as a substitute for coal in cement kilns does less harm to the environment than other end-of-use options.

A critical review of reported emissions studies shows significant variation in all the emission data. There appears to be a definite decrease in NO_x when tires are used a supplemental fuel. SO_2 emissions come primarily from the coal and ore feedstock and do not appear to readily correlate with the use of tires. When burning tires, CO emissions are generally higher. In general, most metal emissions increase, particularly zinc. Emission levels of dioxins/furans reported in the literature show large variability, from 0.1-400 pg I-TEQ/Rm^3 of stack gas. Environment Canada has a long-term goal of 32 pg I-TEQ/Rm^3 with 100 pg I-TEQ/Rm^3 being a reasonable goal at the present time. NPRI has reported dioxin/furan concentrations at Brookfield over the year of 2002–2005 of about 120 pg I-TEQ/Rm^3; recent (2004) measurements at Brookfield show values between 13.2 and 17.2 pg I-TEQ/Rm^3. Since the mechanism and rate of dioxin/furan formation is still largely unknown, and although it is at this point impossible to predict what effect the use of whole tires to replace 20% of the energy content of coal would have on the overall emission of dioxin and furans, it is felt that the overall effect would not be significant. Should kiln upsets be found to result in large dioxin and furan emission values, several control measures are suggested; however, their efficacy is unknown.

A comprehensive testing programme at the Brookfield cement plant is recommended. Initially, baseline testing to determine stack emissions and off-site ground level pollutant concentrations, together with detailed air dispersion modelling, should be undertaken. Following satisfactory baseline testing, pilot testing using whole scrap tires injected mid kiln should be undertaken. The entire testing program should be designed and implemented within a risk management framework.

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1.0 INTRODUCTION

Resource Recovery Fund Board (RRFB) Nova Scotia (2007) is responsible for administration of the used tire management program within the province. On January 26, 2007, RRFB Nova Scotia issued a Media Release stating they had selected Lafarge Canada and its subsidiary partner - Systech Environmental Corp. - to collect and process all scrap tires generated in the province. Lafarge Canada proposes to burn whole used tires as a supplemental fuel at its cement manufacturing plant in Brookfield, Colchester County, NS. Currently, the Brookfield plant burns coal supplemented with waste oil, drilling fluids and shingle flake.

Each year more than 900,000 used tires (an estimated 7,500 t/y)[1] are generated from about 800 registered locations, most being tire retailers. The distribution of used tires in Nova Scotia is shown in Fig. 1.

Fig.1: Distribution of used tires within Nova Scotia (after Lafarge, 2006)

The Lafarge proposal (Lafarge, 2006) plans to utilize 5,300 t/y as supplemental fuel at their Brookfield cement plant with the balance (2,200 t/y) being transported to their sister plant at St. Constant, PQ. The plant at St. Constant currently uses whole tires as supplemental fuel. Systech Environmental Corp. would transport all used tires from Nova Scotia to St. Constant until such time that the Brookfield plant is permitted by Nova Scotia Department of Environment and Labour (NSDEL) to utilize tires as supplementary fuel. Until the contract is finalized and Lafarge meets the necessary approvals from NSEL, RRFB Nova Scotia will continue to collect used tires throughout the province and transport them to approved facilities.

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[1] t/y is metric tonnes per year. 1t = 1,000 kg. The standard ton in the US measurement system is the **short ton**, equal to 2000 pounds (~ 907 kg).

The use of shredded or whole tires as a supplemental fuel is a common practice in industrial processes throughout North America and Europe. Tire-derived fuel (TDF) is used extensively throughout the United States in cement kilns, waste boilers at pulp and paper mills, coal-fired generation plants, waste-to-energy (WtE) processes, and various industrial boiler plants (EPA, 2007; RMA, 2006; EPA, 2005; Clark, *et al.*, 1991).

1.1 Objectives

The objectives of the work undertaken for this report were as follows:

1. To conduct a critical review of the literature with emphasis on the impact of environmental emissions from cement plants utilizing TDF as a supplemental fuel;
2. To review reported emissions from the Brookfield Lafarge cement plant operating on coal and coal supplemented with waste oil, drilling fluids and shingle flake;
3. To estimate changes in the emissions using TDF as a supplemental fuel based on the literature review;
4. To determine the technological and process changes necessary to use TDF as a supplementary fuel at the Brookfield Lafarge cement plant;
5. To identify both process and technological options to mitigate any environmental or health impacts associated with the use of TDF as a supplementary fuel at the Brookfield Lafarge cement plant; and
6. To review the Management of Change (MOC) issues relating to potential hazards and safety that must be addressed using TDF as a supplementary fuel at the Brookfield Lafarge cement plant.

1.2 Team Members

The project team consists of the following Dalhousie University personnel:

- Dr. Michael Pegg, P.Eng. (team leader); Professor and Head, Department of Process Engineering and Applied Science (PEAS)
- Dr. Paul Amyotte, P.Eng.; Professor, PEAS
- Dr. Mort Fels, P.Eng.; Professor, PEAS
- Ms. Crysta Cumming; Environmental Engineering student, PEAS
- Ms. Jacqueline Poushay; Environmental Engineering student, PEAS

1.3 Methodology

The objectives were achieved by a methodology consisting of extensive literature searching, personal contact with various individuals by phone and email, and both solicited and unsolicited stakeholder input. All documents thus identified and cited in the current report reside in the public domain unless otherwise noted.

Journal papers, conference presentations, and technical reports were obtained by means of the following databases and search engines:

- Science Direct (database of journals published by Elsevier)
- COMPENDEX (joint COMPuterized ENgineering InDEX and EI Engineering Meetings database)
- Google (Internet search engine)

At the request of the project team, relevant documentation was also received from the following organizations:

- Nova Scotia Department of Environment and Labour
- Cement Association of Canada
- Lafarge North America
- Citizens Against Burning of Tires (CABOT)

Additionally, all members of the project team participated in a site visit to the Brookfield Lafarge facility on January 4, 2007. The purpose was to gain a better understanding of both the cement making process and the proposed use of TDF as a supplemental fuel in the cement kiln. The visit consisted of a presentation given by Lafarge's Environmental & Alternate Fuels Manager, discussions with key Lafarge personnel (both the Plant Manager and the Operations Manager as well as the Environmental & Alternate Fuels Manager), and a tour of the cement plant and associated areas.

A second site visit was made on 21 February, 2007 by two of the team members. The purpose of this visit was to seek clarification from the Lafarge management team of a number of technical issues, seek further data, tour the electrostatic precipitator (ESP) building and cement kiln dust (CKD) handling facilities, and collect samples of coal, raw feed to the kiln, and CKD for subsequent analyses.

2.0 SCRAP TIRE USAGE

The "Be Tire Smart" campaign (www.betiresmart.ca) promoted by the Canadian Federal Government and the Rubber Association of Canada (RAC) is an example of the principle of "Reduce", one of the the 4Rs of scrap tire management, namely: Reduce; Re-use; Recycle; and Recover (Pehlken and Essadiqi, 2005). Re-use of tires has limited opportunity because of safety issues associated with re-treading passenger vehicle tires. Re-treading is generally limited to truck tires. However, anyone who has driven a highway in Canada will have noticed significant amounts of tread that have separated from trucks implying that re-treading of truck tires has limited success.

Pehlken and Essadiqi (2005) reported that the largest market for scrap tires in Canada during 2003/2004 was rubber crumb. During this time, a total of approximately 240,000 t of scrap tires were processed of which rubber crumb accounted for more than 100,000 t or more than 40% of the total scrap-tire usage market. TDF used in cement kilns or paper mills accounted for 20%, moulded products in recycling plants accounted for 18%, and 13% was shredded. The remainder was baled or stored. About 75% was processed at ambient or cryogenic recycling facilities. Only cement kilns and a limited number of civil engineering applications can utilize whole tires.

Figure 2 shows the distribution of end use of scrap tires in the US for 2005. The percentages are based on the number of tires (259.2 million which represents 86.6% of the 299.2 million tires generated). Table 1 gives the breakdown of end use of scrap tires in the US for 2005 in terms of number of tires (as shown in Fig. 2) and the weight.

Comparing the data from Pehlken and Essadiqi (2005) for 2003/2004 in Canada with that from RMA (2006) for 2005 in the US we see some significant differences in the end use of scrap tires. In Canada crumb rubber accounted for more than 40% of scrap tire usage compared to only 15.3% in the US whereas TDF accounted for 59.3% in the US compared with only 20% in Canada.

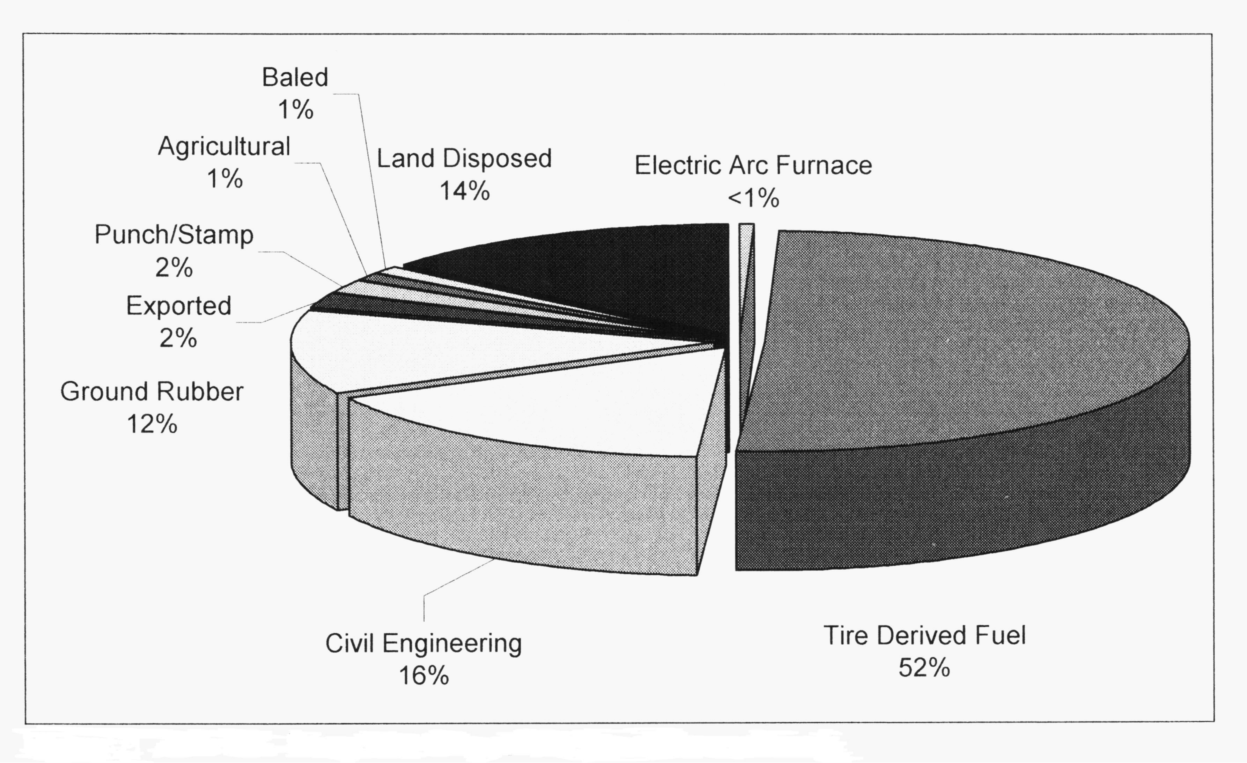

Fig. 2: 2005 US end use of scrap tires (RMA, 2006)

Table 1: 2005 US end use of scrap tires (Adapted from RMA, 2006)

MARKET	# tires (millions)	kilo tonnes	Wt %
Tire Derived Fuel (TDF)	155.09	1945.62	59.31
Civil Engineering	49.22	580.60	17.7
Ground Rubber	37.47	501.24	15.28
Export	6.87	101.60	3.10
Cut/Punched/Stamped	6.13	91.18	2.78
Miscellaneous/Agriculture	3.05	43.17	1.32
Electric Arc Furnaces	1.34	18.35	0.52
TOTAL USE	259.17	3280.53	100.00

Figure 3 shows US TDF market distribution trends from 1990-2007. Cement kilns represent a major user of TDF and the trend has shown a substantial increase. The increased use of TDF in cement kilns is attributed to five main factors (RMA, 2006):

- Increased energy (fuel) prices;
- Favourable cost implications;
- Reduced emissions of nitrogen oxides compared with other fuels; and
- The fact that use of TDF is beginning to be viewed as "routine practice."

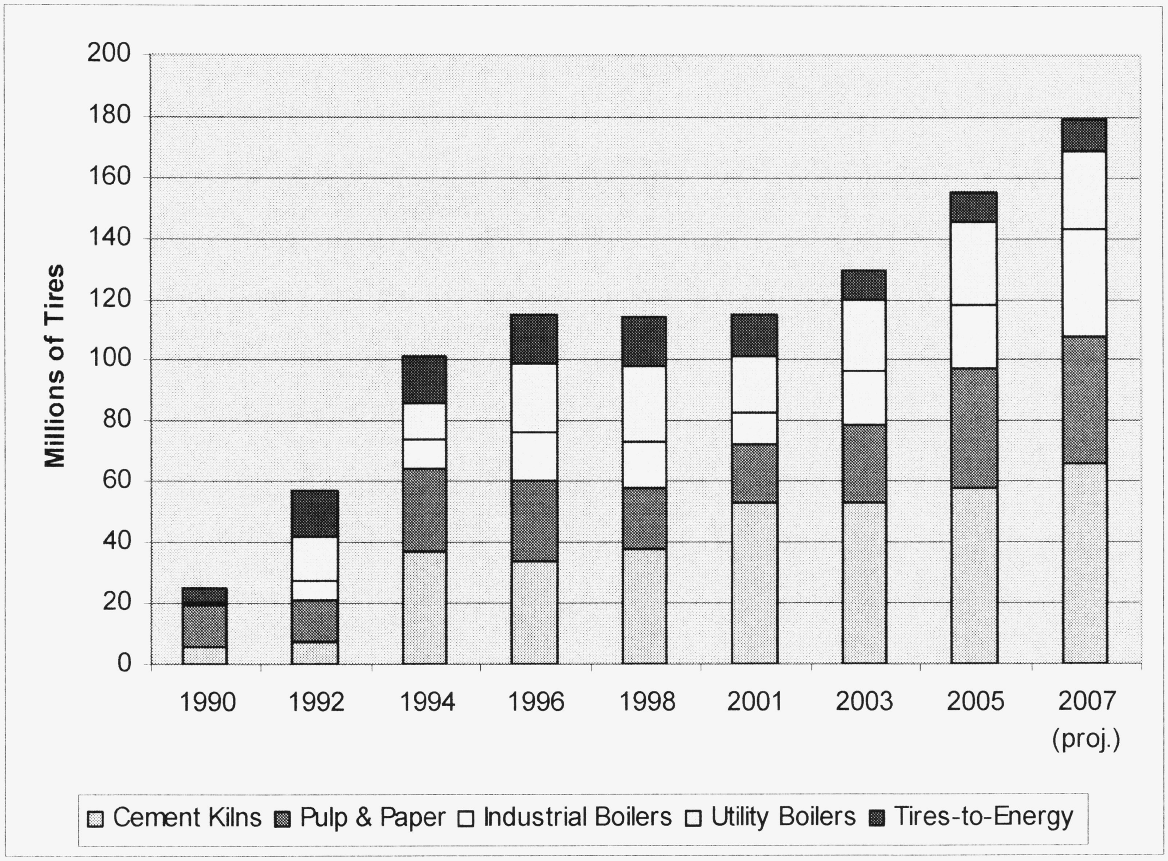

Fig. 3: US TDF market distributions trends, 1990-2007 (RMA, 2007)

The report on scrap tire markets in the US (RMA, 2006) indicates that at the end of 2005 there were 24 pulp and paper mills, 17 electric utility boilers, 16 industrial boilers (particularly in circulating fluidized bed (CFB) boilers), and 1 dedicated tire-to-energy facility using TDF in the US. In Canada there currently appears only to be one pulp and paper mill – Norske Canada's Port Alberni plant (WLAP, 2001), and no utility boilers, industrial boilers or tire-to-energy facilities.

3.0 POTENTIAL INDUSTRIAL APPLICATIONS WITHIN NOVA SCOTIA THAT COULD UTILIZE TDF

One objective of this study was to identify potential industrial applications within Nova Scotia that could utilize TDF as a supplemental fuel. A critical review of literature identified that, other than cement kilns, the largest users of TDF in the United States include pulp and paper mills and electric power utilities (RMA, 2006; Amari, *et al.*, 1999). Nova Scotia is home to three pulp and paper mills, as well as four thermal generating stations that use technology that would be appropriate for combustion of TDF. When available, telephone surveys were conducted with industry stakeholders.

3.1 Pulp and Paper Mills

Pulp and paper production is an energy intensive process that typically requires on-site generation of electricity using boilers and turbines. The fuel source for the production of power is typically wood scrap and bark that remain after the usable part of a tree has been converted to pulp. This material is called “hog” fuel. Due to the energy requirements needed for pulp and paper production, used tires could be combusted in combination with or as a replacement for the addition of gas, oil and coal to hog fuel boilers in the province of Nova Scotia. This could provide an opportunity to reduce energy costs of pulp and paper production in the province, while providing an end use for used tires.

The typical process for generating energy from fuels in a pulp and paper mill boiler begins by feeding bark and wood products in to a pulverizer to obtain easily combustible chips (Barlaz, *et al.*, 1993). This material is distributed across a grate in the spreader stoker at the bottom of the combustion chamber, typically by a mechanical throwing device or an air-fed blower. The fuel is burned on the spreader stoker to produce heat that is used to generate steam used to power a turbine.

To employ used tires as a fuel source in the pulp and paper industry, energy must be generated using approved multi-fuel boilers that contain grates. An additional feed system for tire derived fuel (TDF) would have to be implemented in the fuel feed process, which should include mixing of TDF with hog fuel in appropriate proportions prior to distribution of the fuel feed to the grates in the combustion chamber (Barlaz *et al.*, 1993).

Pulp and paper mills typically use tires that have been de-wired and size reduced to approximately 50-mm x 1.6-mm (Jones, Kennedy and Heberer, 1990). Although de-wiring requirements are dependent on the grate and bottom ash disposal systems, industry typically requires 95% wire removal to reduce metals concentrations and prevent the adherence of metal slag to the boiler grate (Barlaz *et al.*, 1993). De-wired TDF can cost up to 50% more than regular TDF (EPA, 2007).

Environmental concerns related to the use of TDF in pulp and paper mill boilers include the emission of sulphur oxides, nitrous oxides, chlorine and particulate matter which could contain heavy metals. Air emissions from boilers using TDF are highly dependant on air emission control devices, boiler operating conditions and the fraction of total energy supplied by TDF (Barlaz *et al.*, 1993).

In the United States, the second largest application of TDF is the pulp and paper industry, which make use of approximately 25% of total TDF used in the country (estimated from RMA, 2006). Although TDF is not as widely used in Canada, pulp and paper mills such as Norske burn tires as a fuel source (WLAP, 2001). Norske Canada’s Port Alberni Division, British Columbia is permitted to burn up to 5% TDF in its fourth boiler, which operates almost exclusively as a hog fuel boiler. Emissions are regulated under the facility’s operating permit. Particulate emissions from the boiler are monitored for zinc, iron and chloride. The configuration of the fuel feed system and the emission control devices are shown in Fig. 4.

As shown in Fig. 4, TDF is combined with hog fuel prior to being fed to the boiler. Emissions from the boiler are treated by both a multi-cyclone and an electrostatic precipitator before being discharged to the atmosphere.

Thus, TDF is being used as a fuel source in pulp and paper mills in both Canada and the United States to supplement hog fuel used in spreader-stoker fired boilers. Implementation of suitable fuel feed and emission treatment systems in Nova Scotian pulp and paper mills could enable the industry to appropriately use TDF in their spreader stokers.

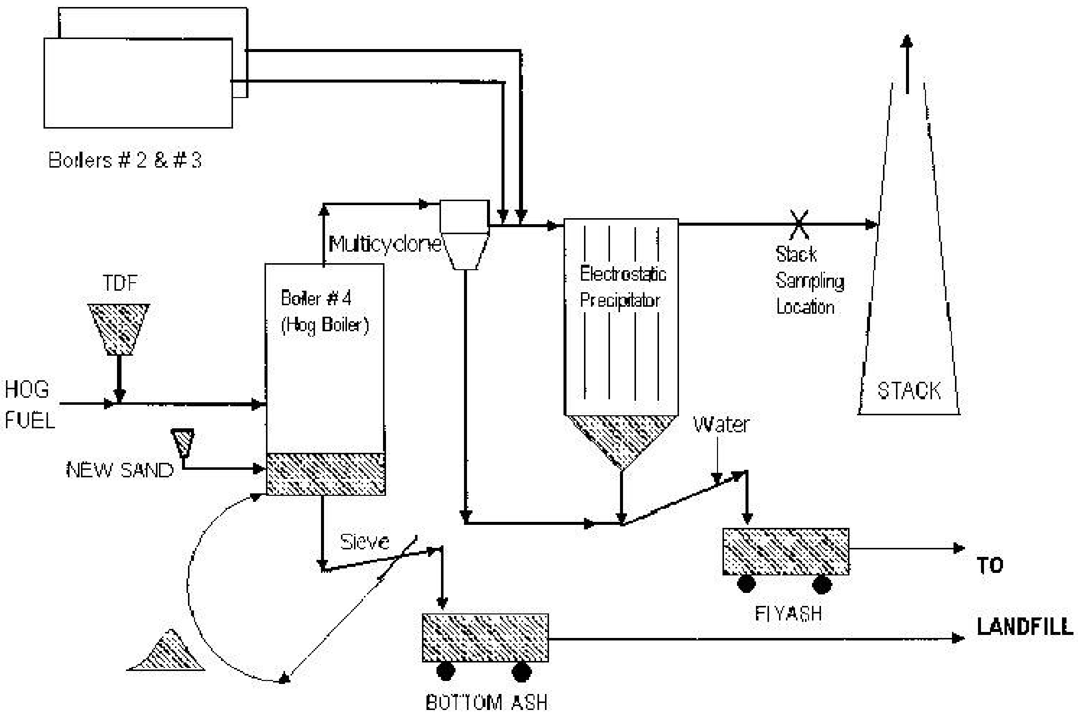

Fig. 4: Norske Canada's Port Alberni Division Steam Boilers and Air Pollution Devices
(from WLAP, 2001: Fig. A-2, p 29)

3.2 Electric Power Utilities

Currently, Nova Scotia Power Incorporated (NSPI) is the main electricity provider in Nova Scotia. In a paper discussing resource recovery from used tires (Amari *et al.*, 1999), it was stated that in 1996 electric power utilities comprised 19% of all TDF users in the United States whereas in 2005 it was 17.4% (estimated from RMA, 2006). From this information, electric power generation in Nova Scotia has been identified as a potential industry that could utilize TDF as a supplemental fuel. Four of NSPI's thermal generating stations use technology that could be considered for the co-combustion of TDF:

- Lingan – using pulverized fuel
- Point Tupper – using pulverized fuel
- Trenton – using pulverized fuel
- Point Aconi – using circulating fluidized bed (CFB) technology.

All four of these plants currently burn a mixture of coal and petroleum coke.

Tires can be used in shredded form or whole, depending on the type of furnace used for combustion. Generally, they need to be reduced in size. In addition to size reduction, some combustion facilities may require the tire to be processed to remove materials in the tire that may prove problematic to the furnace mechanism used for combustion – for example, the metal wire belts found in radial tires (Amari, *et al.,* 1999). Table 2 summarizes scrap tire utilization technologies for electric utilities.

Table 2: Summary of scrap tire utilization technologies
(Amari *et al.*, 1999)

Combustion chamber	Specifications
Cyclone Boiler	Size reduced to 25 x 25 mm or less. Can be co-fired with coal. Requires de-wiring.
Pulverized Coal Boiler	Size reduced to 8 – 25 mm. Can be co-fired with coal. Tests with whole tires are underway.
Fluidized Bed Boiler	Size reduced to 50 – 250 mm. Can be co-fired with coal, gas, and waste wood.

TDF combustion has been attempted at a number of different power plants in the United States, primarily stoker, CFB, and cyclone boilers, due to the difficulty of appropriate size reduction for use in pulverized fuel boilers. There is evidence that TDF has been used in at least one pulverized fuel generating station, although this practice is not common, due to the amount of energy required to produce the pulverized TDF (Hower and Robertson, 2004).

The Tennessee Valley Authority Allen Fossil Plant utilizes 1.25-1.8% TDF blended with sub bituminous and bituminous coal in their two cyclone-fired boiler units. A study of the chemistry and petrology of the fuel revealed that the TDF carbon, which differs from coal carbon in morphology, occurred in both the ash collection system and fly ash (Hower and Robertson, 2004).

Another study compared the chemical composition of the fuel, gases, metals, and metalloids emitted into the air during combustion of coal with those from the co-combustion of coal and TDF at a commercial power plant in Indiana, USA (Gieré *et al.*, 2006). The technology used by the power plant in this study consisted of two spreader-stoker coal boilers with cyclone-like mechanical collectors, an oil and gas-fired unit, and a fluidized bed unit. The emission control system for the spreader-stoker boilers consisted of an electrostatic precipitator. The experiments were conducted using a 95% wt. coal, 5% wt. TDF mixture, with the coal and TDF having a nominal size of approximately 25-mm. The TDF used in the experiments contained synthetic fibres and wires in addition to the rubber (Gieré *et al.*, 2006). No mechanical or handling difficulties of TDF were mentioned; however, Gieré *et al*. express concern over the quantities of metals and metalloids emitted into the air, since in the study, it was estimated that 200 kg As and 180 kg Pb could be emitted over the course of a year, even at a mixture of only 5% TDF.

Scala *et al.*(2003) have analyzed the mechanistic aspects of fluidized bed combustion of TDF. Fluidized bed technology is a favourable choice for TDF combustion because of its inherent design, which allows for fuel flexibility and the ability to achieve a clean and efficient operation. Scala *et al*. (2003) created a fluidized bed combustor model especially suited for high-volatile solid fuel feedings, such as TDF. Results from their experiments and predictions from their model indicate that the efficiency of a fluidized bed combusting TDF depends on the competition between combustion and entrainment of char fines, and the possibility of volatiles burning in the freeboard region of the boiler, instead of the bed. Scala *et al.* (2003) concluded that volatiles bypassing the bed may lead to troublesome operation of the unit.

The use of TDF in electric power generating stations in Nova Scotia is limited due to the technology being used. Pulverized fuel-fired generating stations, such as the Lingan plant, are not candidates for the burning of TDF, due to the size requirements of TDF when used in conjunction with pulverized fuel. TDF poses other problems for CFB generating stations; the tires must be chopped to a similar size as the conventional fuel. As well, the composition of the TDF poses a problem for the ash-handling systems of generating stations. The steel wires of the tires pose a materials handling problem, as they may clump and foul the ash-handling system. TDF also contains a relatively high carbon content, which will increase the amount of ash produced by the fuel. Because of these possible problems, the use of TDF in electric power generating stations in Nova Scotia is not favourable.

4.0 CRITICAL REVIEW OF LITERATURE ON EMISSIONS FROM CEMENT PLANTS

To provide a context for undertaking a critical review of the literature pertaining to utilization of TDF as a supplemental fuel and the impact of environmental emissions from cement plants, we reviewed literature pertaining to the end use of used tires.

4.1 Life Cycle Analysis of Used Tires

Life Cycle Analysis (LCA) is a tool that is used to evaluate the impact of a product in terms of its material, energy and waste flows. As shown in Fig. 5, LCA follows the inputs and outputs of the processes necessary for the existence of a product, from acquisition of raw materials to its final use or disposal. LCA has also been used as a tool to compare the environmental impact of different end-use options for products such as tires.

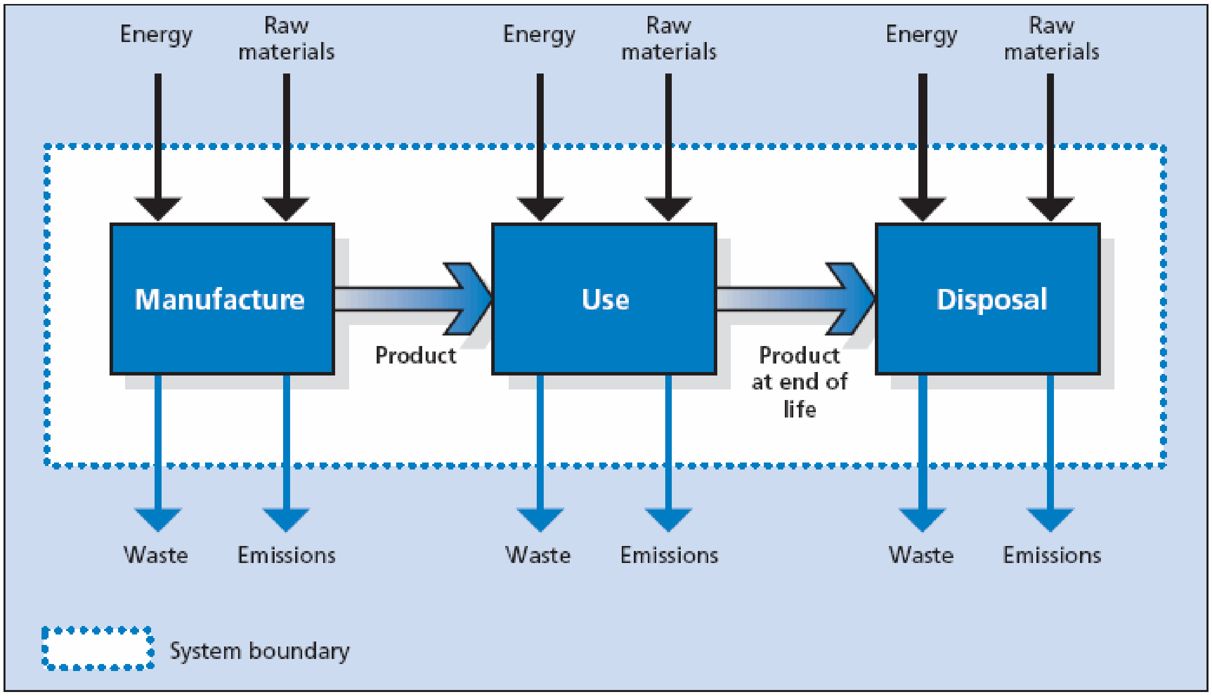

Fig. 5: Processes typically considered when conducting an LCA for a product
(AEA Technology, 2000))

Here we review three LCA from literature that have been conducted to evaluate the post-consumer environmental impact of passenger tires. LCA gives a basis for determining the expected environmental impact of the use of tires as a fuel in the Lafarge cement kiln in Brookfield Nova Scotia in terms of material and energy requirements, as well as resulting wastes and emissions.

Corti and Lombardi (2004) conducted a LCA of four options for the end-use of used tires; namely:

- Mechanical Pulverization Process (MPP);
- Cryogenic Pulverization Process (CPP);
- Waste-to-Energy (WtE); and
- use of tires as a supplemental fuel in cement kilns.

Thus, a basis is provided for comparing the life cycle effects of several end-use alternatives for waste tires. Their analysis is based on 1 tonne (1,000 kg) of tires assuming all tires have equal properties. In each case, inputs and outputs of corresponding processes were analyzed to determine their environmental impacts. Inventory analysis was also performed to quantify the magnitude of the inputs and outputs involved in each process. Corti and Lombardi (2004) then used the Eco-Indicator '95 methodology to assess the relative environmental impacts of each of the four end-use options in terms of 'Eco-Points'.

The IVL Swedish Environmental Research Institute Ltd (Aman, 2006) compared six end-uses for tires based on 1 tonne of used tires. These were:

- incineration in cement kilns;
- recycling granulated tires in artificial football fields;
- reuse as a drainage material for landfill capping;
- incineration in a district heating plant;
- recycling granulated tires in asphalt; and
- reuse as a filling material in noise banks.

Continental, a tire manufacturing company based in Germany, conducted an LCA on tires from cradle to grave. As part of the LCA they evaluated options for tire recycling or reuse. The Continental (Kromer *et al.,* 1999) LCA report evaluated three end-uses for used tires:

- full re-treading;
- use as a fuel in cement kilns; and
- energy generation in power stations.

Their report did not aim to compare these three activities; instead, comparisons were made between the use of tires in these applications and the use of raw materials or standard fuels. For the purpose of our study, the comparison between tires and coal as fuel in cement kilns was considered. The analysis for Continental's comparison is based on the amount of material required to supply 25% of the total energy requirements for a cement kiln.

4.1.1 The Corti and Lombardi LCA Comparison

1. Mechanical Pulverization

As identified by Corti and Lombardi (2004), there are three processes involved in generating mechanically pulverized tires: grinding, crushing and the pulverization itself. Grinding reduces the tires to 70 to 100-mm pieces and acts as a method for removing steel belting within the tires.

Tires are transported from one process to the next along conveyor belts. Magnets are used to remove metal scrap. The second step further reduces the size of the tires to 20 mm pieces using crushing equipment. Tires are then reduced to an approximate size of 1 mm in a pulverization unit that contains rotating blades. This process of mechanical size reduction of tires is shown schematically in Fig. 6. Table 3 shows the quantities of inputs and outputs from each of the size reduction steps shown in Fig. 6.

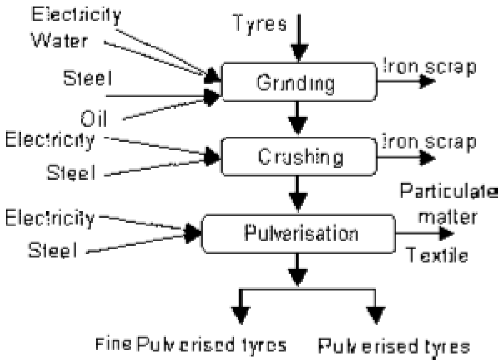

Fig. 6: Production of pulverized tires by mechanical size reduction
(Corti and Lombardi, 2004)

Table 3: Inputs and outputs for the production of pulverized tires by mechanical size reduction (Corti and Lombardi, 2004)

Grinding Process		
Input	**Output**	**Amount**
Tires		1000 kg
Electricity		170 MJ
Water		150 kg
Steel		0.230 kg
Oil		0.011 kg
	Ground tires	966 kg
	Iron scrap	34 kg
Crushing Process		
Input	**Output**	**Amount**
Ground tires		1000 kg
Electricity		573 MJ
Steel		0.010 kg
	Crushed tire 16x16 mm	750 kg
	Iron scrap	250 kg
Mechanical Pulverization Process		
Input	**Output**	**Amount**
Crushed tires 16x16 mm		1000 kg
Electricity		513 MJ
Steel		0.278 kg
	Fine pulverized tires (<0.7 mm)	630 kg
	Textile fibres	60 kg
	Particulate matter	0.026 kg

2. Cryogenic Pulverization

Tires can be further size reduced using cryogenic pulverization. There are two steps involved in generating cryogenically pulverized tire crumb; the first of which is production of pulverized tires by mechanical size reduction and the second is cryogenic pulverization. The processes involved in making cryogenically pulverized tires are shown in Fig. 7. This analysis assumes that cryogenic pulverization requires initial grinding, crushing and mechanical pulverization. The quantified inputs and outputs of grinding, crushing and mechanical pulverization have already been presented in Table 3. Quantified inputs and outputs for cryogenic pulverization alone are shown in Table 4. Cryogenic pulverization involves cooling the tire crumb to a temperature at which is can more easily be cracked into smaller fragments. The Corti and Lombardi (2004) study assumes that this cooling is performed by liquid nitrogen.

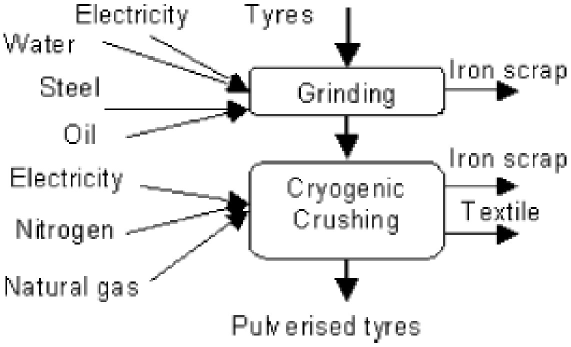

Fig. 7: Processes for cryogenic crushing of tires
(Corti and Lombardi, 2004)

Table 4: Inputs and outputs of the cryogenic pulverization process
(Corti and Lombardi, 2004)

Input	Output	Amount
Ground Tires		1000 kg
Electricity		180 MJ
Nitrogen		703 kg
Natural Gas		1.55 m^3
	Pulverized Tires	675 kg
	Iron Scrap	265 kg
	Textile Fabrics	60 kg

3. Waste-to-Energy (WtE)

Scrap tires can be used to produce electrical power in WtE facilities. Corti and Lombardi (2004) considered the life cycle impact of tires burned in a conventional moving grate municipal solid waste (MSW) incinerator. Their LCA was based on processes that recover the heat released during combustion to produce steam in a conventional heat recovery steam generator. To prevent the release of harmful emissions, the WtE process under consideration included both a spray absorption (SA) unit and a fabric filter (FF). Figure 8 shows the processes involved in generating electrical energy from waste tires. Quantified inputs and outputs for the WtE process are shown in Table 5.

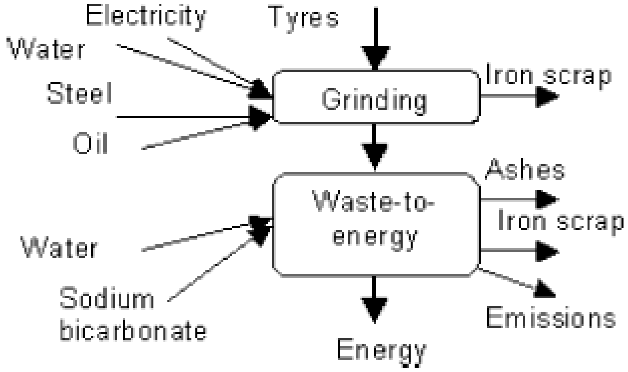

Fig. 8: Processes for tire Waste-to-Energy use
(Corti and Lombardi, 2004)

Table 5: Inputs and outputs for waste-to-energy tire use (Corti and Lombardi, 2004)

Input	Output	Amount
Ground tires		1000 kg
Electricity		413 kJ
Sodium bicarbonate		120 kg
	Electricity	476 MJ
	Ashes	89 kg
	Iron scrap	220 kg
	CO_2	-509 kg
	HCl	17.6 g
	SO_2	28.1 g
	PM	15.4 g
	NO_x	288 g
	CO	67.3 g
	Cd	3.85 mg
	Hg	3.85 mg
	Pb	1.92 mg
	IPA	3.85 mg
	Sum of Sb, As, Cr, Cu, Co, Mn, Ni, V, Sn	9.61 mg

4. Fuel in Cement Kilns

Corti and Lombardi (2004) also conducted an LCA on the use of waste tires as a fuel source (TDF) in cement kilns. Their comparison considered the TDF in the form of ground tires as a supplement to coal. In this application, it was concluded that iron, a material that is typically added to the kiln feed, was provided in part by the iron in the tire belting. Thus, iron was saved as a result of the use of TDF. The processes included in this LCA of tire use in cement kilns are shown in Fig. 9. Quantified inputs and outputs for co-combustion of TDF with coal in cement kilns are shown in Table 6 and the additional emission factors are given in Table 7.

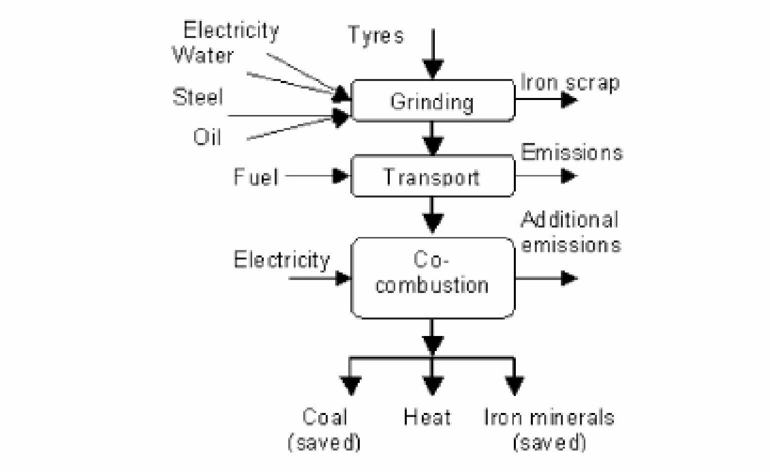

Fig. 9: Use of tires in cement kilns
(Corti and Lombardi, 2004)

Table 6: Inputs and outputs for the co-combustion of coal and TDF in a cement kiln
(Corti and Lombardi, 2004)

Input	Output	Amount
Tires		1000 kg
Diesel		6.05 kg
Electricity		6 MJ
Coal		-877 kg
Iron Materials		-250 kg
	Emissions	Presented in Table 7

Table 7: Additional emission factors in co-combustion of coal and TDF in a cement kiln
(Corti and Lombardi, 2004)

Fuel	SO_2	NO_x	NMVOC[2]	CH_4	CO	CO_2	N_2O	PM	Cr	Pb
g/GJ										
Coal	25	575	15	15		86	3.5	2.88	0.001	0.000462
Tires		-15 to 30%	-54%		2 g/GJ		1	1	174%	174%
Additional emission factors (g/ton tires)										
Tires		-21 to 43	-2		390				0.184	0.0851

Eco-Indicator '95

Eco-Indicator '95 (Goedkoop, undated) was developed by PRé Consultants, Amersfoort, NL, (http://www.pre.nl/pre/default.htm) as both a science-based LCA methodology and a method for evaluating alternatives for sustainable design. It has since been updated and released as Eco-Indicator '99 (Goedkoop and Spriensma, 2001). Corti and Lombardi (2004) used Eco-Indicator '95 to determine quantitative values for the environmental impacts of tire end-use options. The methodology allows the user to determine a quantitative approximation of the environmental effect of a process or activity. Eco-Indicator '95 parameters can be assigned either a negative or positive value depending on whether environmental damage in the area has been increased or decreased. Thus, positive values are interpreted as adding to environmental harm, while negative

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[2] Non-Methane Volatile Organic Compounds

values indicate that environmental harm has been avoided. Factors that contribute to environmental effects were normalized to unity. The parameters and units used in Corti and Lombardi's (2004) Eco-Indicator '95 analysis are shown in Table 8.

Table 8: Criteria Used by Corti and Lombardi (2004) in their Eco-Indicator '95 based LCA
(Corti and Lombardi, 2004)

Category	Environmental Effect		Units
Environmental Effect	1	Greenhouse effect	kg CO_2
	2	Ozone layer depletion	g CFC11
	3	Acidification	kg SO_2
	4	Eutrophication	g PO_4
Human Health	5	Heavy metals	g Pb
	6	Carcinogens	g Benzo[a]pyrene
	7	Winter Smog	kg SPM
	8	Summer Smog	g C_2H_4
	9	Pesticides	g Active substances
Resource Depletion	10	Water Consumption	kg
	11	Energy	MJ
	12	Solid Waste	kg

Results from this analysis were weighted in terms of the distance of the severity of the effect in accepted target values, as outlined in Eco-Indicator '95 methodology.

Results of the Corti and Lombardi End-Use Comparison

The Corti and Lombardi study concluded that of the four end-uses considered, the least environmentally harmful option for used tires is fuel substitution in cement kilns. The results of the Eco-Indicator '95 based analysis are shown in Fig. 10. It was evident from their study that cryogenic pulverization has the most negative impact on the environment, and that energy recovery applications have less impact on the environment than rubber recycling applications.

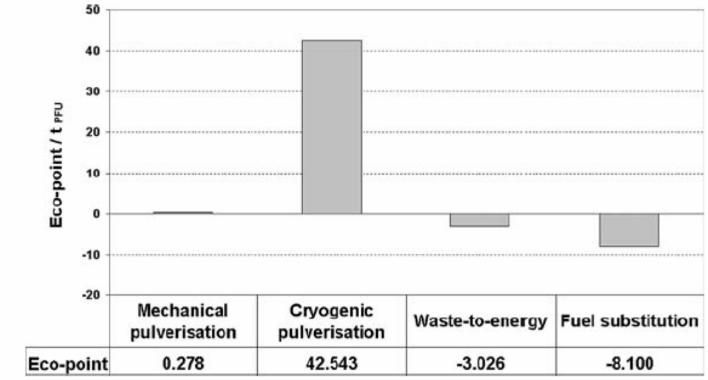

Fig. 10: Eco-point values assigned by Corti and Lombardi (2004) to tire end-use options

Corti and Lombardi (2004) conducted a sensitivity analysis of the criteria for evaluating the environmental effects. This was done in order to determine how uncertainty in data and assumptions might affect the overall conclusion. The sensitivity analysis supported the conclusion that even when considering uncertainty inherent in the data, use of tires in cement kilns is still the least environmentally harmful option.

4.1.2 IVL Swedish Environmental Research Institute LCA Comparison

In this analysis (Aman, 2006) included the inputs and outputs of the processes included in each of the six options being compared. This included provisions for the materials used and materials replaced as well as the energy and resources required for their production and transportation. The environmental parameters included in this analysis are shown in Table 9.

Table 9: IVL Swedish Environmental Research Institute LCA comparison parameters
(Aman, 2006)

Inputs	**Outputs**
Natural Resources	*Emissions*
Crude Oil	Carbon Dioxide
Natural Gas	Sulphur Dioxide
Uranium	Nitrogen Oxides
Limestone	Methane
Iron Ore	Hydrocarbons
	Heavy Metals

The parameters listed in Table 9 were evaluated on the basis of their application to three life cycle impact assessment criteria: (1) global warming; (2) acidification; and (3) eutrophication and photochemical oxidant formation and water emissions caused by leaching. Human and eco-toxicity criteria were not included in this comparison to avoid their inherent uncertainty.

Results of the IVL Swedish Environmental Research Institute LCA Comparison

Results of the IVL comparison are shown in Figs. 11-13.

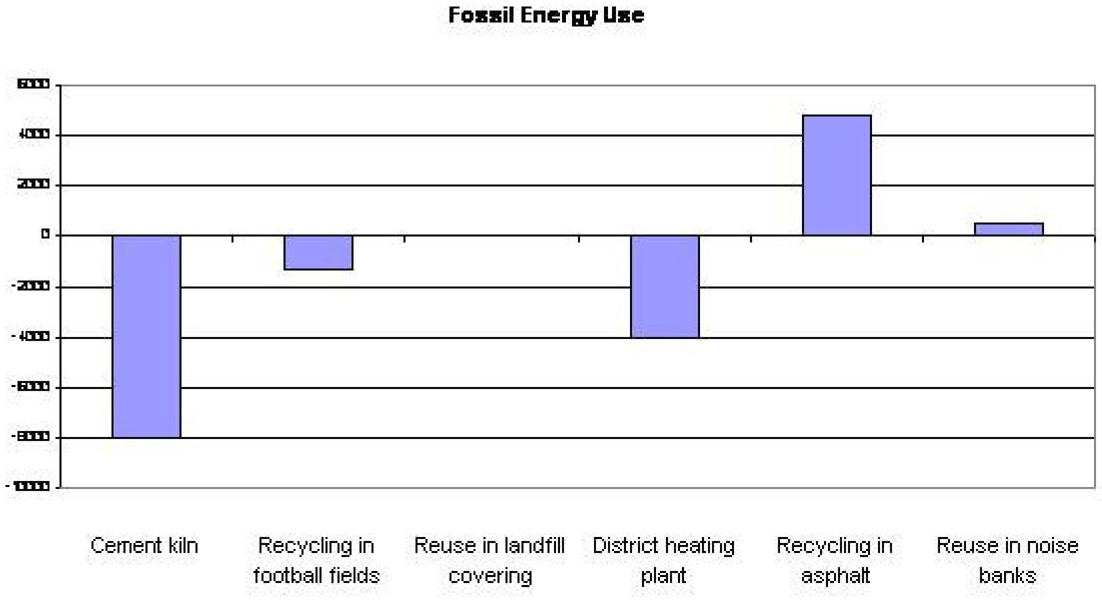

Fig. 11: IVL Results for tire end-use LCA comparison of fossil energy use
(after Aman, 2006)

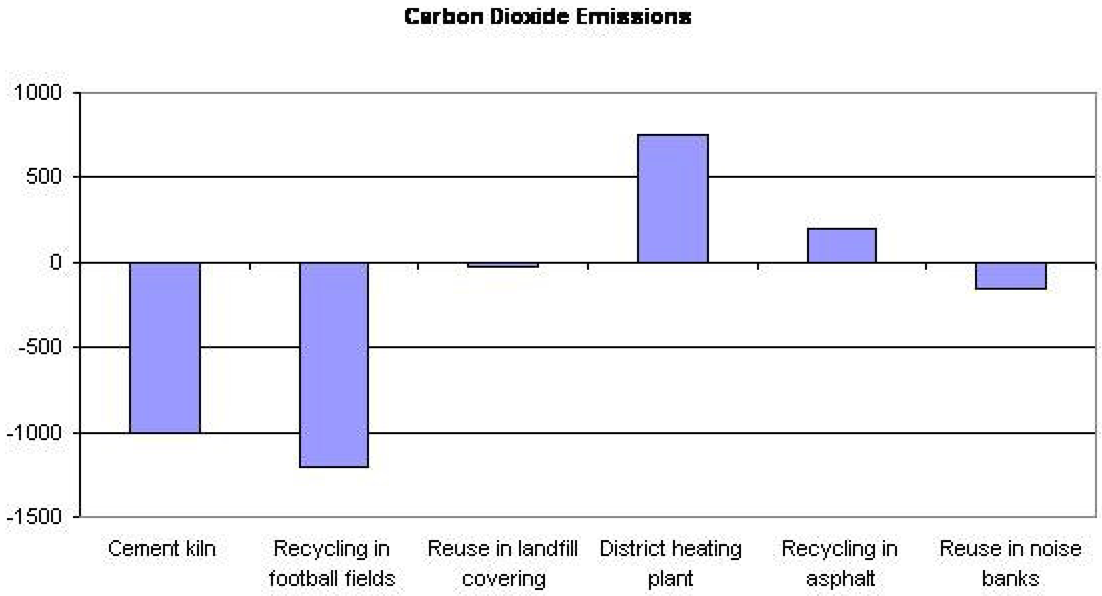

Fig. 12: IVL Results for tire end-use LCA comparison of CO_2 emissions
(after Aman, 2006)

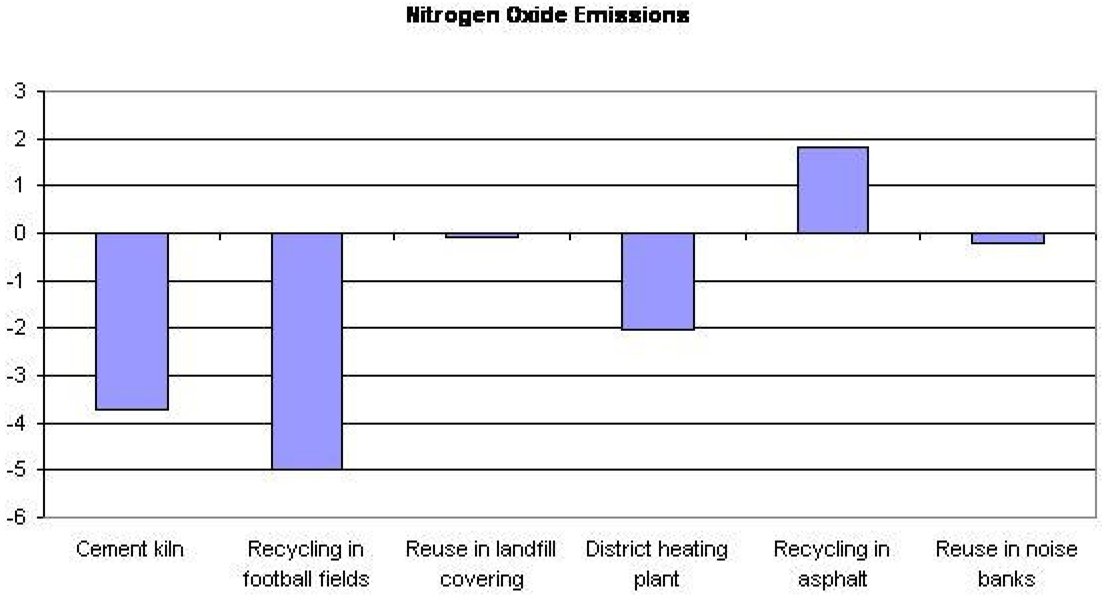

Fig. 13: IVL Results of tire end-use LCA comparison of NO_x emissions
(after Aman, 2006)

The study concluded that recycling granulated tires in artificial football fields results in the least environmental harm. The second least harmful option is the use of tires as a fuel source in cement kilns. Reuse of tires in noise banks, reuse in landfill covering and use in district heating plants tied as being the third least harmful options. Recycling tires in asphalt applications was determined to be the most environmentally harmful end use of used tires.

4.1.3 Continental LCA Comparison

The LCA of tires by Kromer *et al.* (1999) concentrated mainly on the environmental effects of tires during manufacturing, transport and use. The report also included LCA of three recycling options for used tires: re-treading and reuse, use in cement kilns, use in energy generation plants. As mentioned previously, the aim of the study was not to compare end-use options, but instead to compare the use of tires to the use of conventional materials in the same application. Here we focus on their comparison of used tires and coal as fuels in cement kilns.

The Continental LCA comparison is based on tires as an alternative source for 25% of the energy required by cement kilns. This was compared to coal as a source for the same amount of energy.

Results of the Continental LCA Comparison

Results of their comparison of inputs, outputs and environmental effects are shown in Fig. 14.

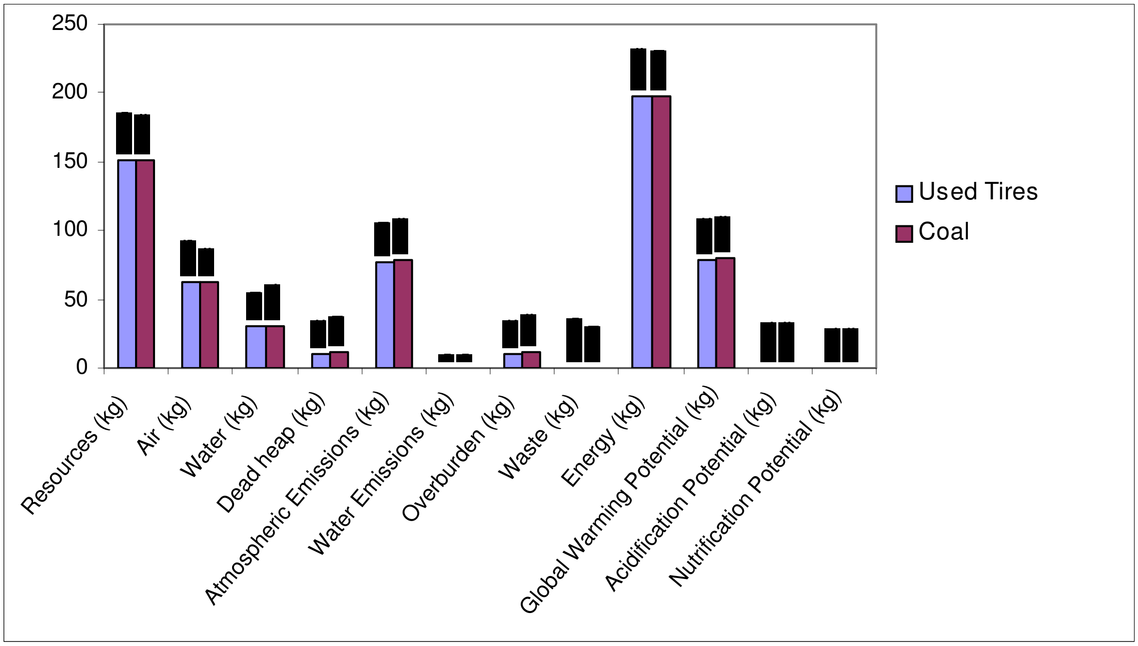

Figure 14: Continental comparison of cement kiln fuels (after Kromer *et al.*, 1999)

Figure 14 indicates that coal and tires are relatively equivalent in each of the categories, however, tires result in slightly lower input requirements, outputs and overall environmental impacts.

The overarching conclusion of the Continental LCA comparison was that tire use in cement kilns as an alternative to coal does not affect input, output or environmental effect parameters to any great extent and thus, the environmental effect of using used tires in cement kilns can be regarded as neutral. Specific conclusions reached in the Continental study are as follows:

- Using tires in cement kilns may reduce the generation of dead heap and overburden by up to 14% in each case. This can be attributed to lower coal mining requirements.
- Tire use in cement kilns may produce 1.4% less atmospheric emissions than coal. This is because tires generally have lower carbon, sulphur and nitrogen content than the coal used, which can result in avoided CO_2, SO_2 and NO_x emissions.

- Lower emissions from tire use contribute to a 1.9% reduction in global warming potential, 1.9% reduction in acidification potential, and 1.7% reduction in nutrification potential.
- 0.5% reduction in raw material requirements may be achieved when tires are used instead of coal.
- Slag and ash produced during combustion may be reduced by using tires, resulting in 4.2% less waste than using coal in the same application.

4.1.4 Applicability of LCA Results

It should be assumed that studies conducted on processes and plants other than the subject plant in Brookfield Nova Scotia should be used as tools in decision making, but should not be interpreted as directly transferable proofs. It is important to note the deficiencies in these studies so that the conclusions that they present can be assessed in terms of the Brookfield Lafarge plant.

1. Data and conclusions may be specific to regional equipment and environmental standards

The three LCA comparisons considered in this report do not give details about the operating parameters of the plants or the types of equipment used in the processes. The LCA comparison completed by Corti and Lombardi (2004) is based on Italian data that has been averaged over a one year period. Although this study does indicate some of the equipment used in the processes, it fails to address the emission control equipment for cement kilns. The IVL Swedish Environmental Research Institute report (Aman, 2006) is based on Swedish data and, again, does not describe equipment used or environmental standards that apply to the comparison. Continental's LCA comparison (Kromer *et al.*, 1999) is based on German data and does not specify any of the equipment used by the cement industry.

For the purpose of this study, it is of particular concern that the report does not mention the emission control devices used on the cement kilns that were included in the evaluation. Emission control devices can drastically vary the amount of air emissions released from cement plants and it is quite possible that emission control devices used in Italian cement kilns vary at least slightly from the devices employed in Canada. Because the control devices have not been characterized, it is difficult to interpret the results in terms of the Brookfield Lafarge plant.

It is clear that the conclusions derived from these reports are only directly applicable as averages for the European tire management industry. The results can be used for qualitative purposes, but data is not directly transferable to other parts of the world. With this said, it should also be noted that studies of this kind are relatively new and have not, to our knowledge, been successfully completed for Canadian used tire management options. Therefore, these studies are useful tools.

2. LCA methodology

The Corti and Lombardi study was written in 2004, however, it employed the older version of the Eco-Indicator method: Eco-Indicator '95 (Goedkoop, undated.). This indicator was one of the first LCA based techniques for evaluating the environmental effects incurred by a product's existence. Experience using this methodology has yielded an improved version of the same approach, which has been released by PRé Consultants as Eco-Indicator '99 (Goedkoop and Spriensma, 2001). Thus, it is possible that the results obtained using the older Eco-Indicator may not be synonymous to results obtained using the newer version; particularly in terms of the weighting factors applied to the environmental effect parameters.

It should also be noted that Eco-Indicator '95 is based on European trends and process data. This further supports the conclusion that results obtained using this methodology may not be directly applicable to North America, depending mainly on differences in standards and managerial approaches.

The LCA approaches adopted by IVL and Continental are based on quantifying the average inputs and outputs of applicable processes. Results from this type of analysis are highly dependant on operating parameters of the plants under consideration. Therefore, this type of LCA gives a relative comparison of the environmental effects but does not give enough detail to be able to evaluate a particular application for use tires, such as the Brookfield Lafarge plant.

4.1.5 Summary of LCA results

From these three LCA, it has been determined that tire use as a supplemental fuel in cement kilns shows promise in terms of avoiding negative environmental effects. The three studies, each based on data from different countries in Europe all reached the same conclusion: used tires as a supplemental fuel in cement kilns is one of the two best options available for the end-use of scrap tires. Compared to coal, LCA indicate that used tires are a fuel source that could slightly reduce environmental effects on some fronts, while slightly increasing others.

Through use of tires in cement kilns environmental effects were shown to decrease in the following areas:

- Decreased use of coal, a fossil fuel source;
- Decreased production of dead heap and overburden created during coal mining;
- Reduction in emissions of: CO_2, NO_x, SO_2, and non-methane volatile organic compounds;
- Reduced use of raw materials, particularly the addition of iron ore to the cement production process which is supplied by the addition of whole tires; and
- Smaller volumes of slag and ash produced.

Through use of tires in cement kilns environmental effects were shown to increase emissions of chromium and lead.

Results from the cited LCA do not specifically evaluate quantitative life cycle effects of using tires as a supplemental fuel source at the Brookfield Lafarge plant, although they do indicate the expected trends.

4.2 Emissions from Cement Plants

Since the conclusions from LCA demonstrate that using TDF as a supplementary fuel in cement kilns has the least harmful impact on the environment, and to fulfil the first objective, studies of emissions from cement kilns were reviewed. It is apparent that numerous studies have been done on the subject of using tires as a partial substitute fuel in cement kilns. The following summarizes the major sources which list these studies:

1. CANTOX (2006) {CANTOX Environmental}, Mississauga, Ontario, *"Literature Review & Assessment of Public Health Impacts of Alternative Fuel Use in the Cement Industry"*, report to the Cement Association of Canada, September 2006. This report contains a summary of 26 emission studies. In about one-half of the cases, actual emission data are given. Conclusions and comments are also included.

2. Rubber Manufacturing Association (RMA, 2007), *"Publications: Scrap Tires"* Retrieved January 18, 2007 from:

   www.rma.org/publications/scrap_tires/index.cfm?CategoryID=572

   This publication gives 47 titles of reports available through the association. Of these, four deal directly with use of tires in rotary cement kilns (TDF-016, TDF-039, TDF-052 and TDF-047).

3. Portland Cement Association (PCA, 2004), *"Use of Waste Tires in Cement Manufacture"*, PCA Library Bibliography Series No. 12 (LB12), (2004). The list contains 170 references specifically dealing with alternative fuels in a cement kiln. Many of these references are conference proceedings.

4.2.1 Review of Emission Studies

The emissions which are reported by most studies are:

1. **NO_x:** Nitrogen oxides are formed mostly by the reaction of nitrogen and oxygen in the air at high temperatures of the combustion process.
2. **SO_2:** Sulphur dioxide arises from burning the sulphur in the fuel and from the oxidation of sulphides in the cement ore itself. Some of the SO_2 is absorbed in the cement because of the alkalinity. Tires have about 1% (w/w) sulphur.
3. **PM:** Sources of particulate matter are the cement itself and the ash in the fuel. All kilns have control devices (electrostatic precipitators or baghouses) which remove 95+ % of the kiln emissions. Tires contain about 5% ash.
4. **CO:** carbon monoxide is formed by incomplete combustion of the carbon in the fuel.
5. **Metals:** There are a host of metals which are reported in an emission inventory. Major ones of importance are Hg, Cd, Tl, Sb, As, Cu, Cr, Mn, Ni, Zn, Fe. The source of these metals is, naturally, the cement raw ore itself; however, petroleum and petroleum-derived products also contain these elements. Analysis of the ash from tires (5% by weight) indicates that the major metallic constituent is iron (from the belts) at 96%, with Cr (0.5%), Mn (0.4%), Cu (0.3%) and Zn (0.1%) as minor constituents.
6. **Dioxins and Furans**: These chlorine-containing ring compounds arise from incomplete combustion of an organic fuel when there are chlorine-containing compounds present. High temperatures (> 1000°C) and residence times greater than a few seconds essentially result in decomposition of these compounds. As a result, concentrations reported are 10^{-6} to 10^{-12} times those of the larger emissions such as NO_x, SO_2 and CO.

Tables 10 and 11 summarize results of emission data for cement kilns taken from literature cited in the CANTOX (2006), RMA (2007), and PCA (2004) reports.

The following observations are noteworthy:

1. There is quite a large variation in all the emission data.

2. It appears that in the case of NO_x, there is a definite trend for this pollutant to decrease when tires are used as a supplemental fuel. This observation has been made by several researchers (average of 40% decrease; $\sigma = 20\%$)[3].
3. The effect of burning tires (1% S) on the SO_2 emission does not seem to correlate; most of the SO_2 would come from the ore and the coal since the tires not only have relatively low sulphur content, but also replace only about 20% of the fuel.
4. CO emissions in most cases are higher (average 35% higher, $\sigma = 76\%$). This would indicate that the tires produce a fuel-rich zone as they undergo pyrolysis leading to a more incomplete combustion and a lower flame temperature in the kiln (consistent with the lower NO_x emissions).

It is not possible to make conclusions about metal emissions from the limited numerical data in the tables. Except for iron (which is normally added to the cement mix anyway), metal content of tires is small and probably their effect on the emission level would be small.

Table 10: Emission Factors (kg/tonne cement)

Reference[4]	NO_x		SO_x		PM	
	w/o tires[5]	w tires[6]	w/o tires	w tires	w/o tires	w tires
1	3.00		4.90		0.50	
2a			0.53	0.41	1.87	1.67
2b	4.96	3.9	5.27	3.13	0.19	0.23
3	2.94	2.63	1.17	1.45	0.17	0.18
Reference	CO		Cl		Metals	
	w/o tires	w tires	w/o tires	w tires	w/o tires	w tires
1	0.11		0.36		4.7E-04	
2a						
2b	0.52	1.22				
3	0.26	0.36	1.6E-02	2.4E-02	3.75E-04	9.71E-04
Reference	Fe		Zn		TOC	
	w/o tires	w tires	w/o tires	w tires	w/o tires	w tires
1	8.5E-03		2.74E-04		0.014	
2a					2.0E-04	2.0E-04
2b					2.8E-04	2.2E-04
3	1.5E-03	2.74E-03	3.10E-04	2.25E-04	2.76E-04	2.46E-04
Reference	PCDD/F					
	w/o tires	w tires				
1	1.40E-09					
2a						
2b						
3	1.76E-06	9.40E-07				

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[3] σ = standard deviation

[4] The references are: **1**. EPA (2007); **2a**. CANTOX (2006) Table A-6; **2b**. CANTOX (2006) Table A-6a; and **3**. Carrasco, Bredin and Heitz (2002).

[5] Emission factor without tires as supplemental fuel

[6] Emission factor using tires as supplemental fuel

Table 11: Emission Data for Cement Kilns

Reference CANTOX (2006)	units	NO_x		SO_x		PM	
		w/o tires	w tires	w/o tires	w tires	w/o tires	w tires
A-2[7]	mg/m^3 stack gas	692	430	27.3	10.4	14.9	10.1
A-3	mg/m^3 stack gas	915	503	24	9	37.2	20.3
A-4	mg/m^3 stack gas	1754.4	1483.9	696.8	905.2	99.2	106.5
A-7	mg/m^3 stack gas						
A-11	mg/m^3 stack gas	281	281			2.2	2.2
A-12 (1)[8]	$\mu g/m^3$ stack gas	1.8	0.49	0.4	3.5	0.002	0.012
A-12 (2)[9]	$\mu g/m^3$ stack gas	2.5	1.3	0.6	5.4	0.003	0.017
A-14	mg/m^3 stack gas	114				25.9	

Reference CANTOX (2006)	units	CO		Cl		Metals	
		w/o tires	w tires	w/o tires	w tires	w/o tires	w tires
A-2	mg/m^3 stack gas	249	445	0.7	0.28	0.12	0.012
A-3	mg/m^3 stack gas	558	857	0.9	0.95	0.028	0.021
A-4	mg/m^3 stack gas	155.4	228	9.4	15.3		
A-7	mg/m^3 stack gas					0.042	0.042
A-11	mg/m^3 stack gas	225	225				
A-12 (1)	$\mu g/m^3$ stack gas	7	3				
A-12 (2)	$\mu g/m^3$ stack gas	8	4				
A-14	mg/m^3 stack gas	25.9					
A-26	mg/m^3 stack gas	67.4	161.1				

Reference CANTOX (2006)	units	Fe		Zn		TOC	
		w/o tires	w tires	w/o tires	w tires	w/o tires	w tires
A-2	mg/m^3 stack gas					14.2	61.5
A-4	mg/m^3 stack gas	0.87	1.86				
A-7	mg/m^3 stack gas			0.022	0.062		

Reference CANTOX (2006)	units	PCDD/F	
		w/o tires	w tires
A-1	mg/m^3 stack gas		9.6E-04
A-2	mg/m^3 stack gas	4.80E-08	1.40E-09

The authors of the CANTOX (2006) report did present conclusions of their own as well as conclusions from the various studies. Below is a qualitative summary of the findings of the original authors of the study (based on a review of the cited references). These are presented since they offer a definite "flavour" of what is current thought on the matter of using tires as alternate fuel.

(i) A study of a cement plant in Spain using tires as supplemental fuel, reported PCDD/F (dioxins and furans) emissions remain below the limit established by the EU Directive of 100 pg I-TEQ/Rm^3 (Abad *et al.*, 2004).

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[7] These are the Table numbers in the CANTOX (2006) report from which data was abstracted

[8] Data in $\mu g/m^3$ from operating 1 kiln

[9] Data in $\mu g/m^3$ from operating 2 kilns

(ii) Carrasco *et al.* (1998) compared the rate of emission (mg/m^3 of stack gases) and the atmospheric dispersion of several pollutants from a cement plant in Quebec (Lafarge's St. Constant facility) using coal, and a mixture of 80% coal and 20% whole tires. Predicted maximum (ground level) concentrations were all well within environmental standards. Emissions of PM increased by 7% from the kiln stacks and 15% from the clinker cooling unit stack. For gaseous emissions, CO increased by 47%, SO_2 by 30% and NO_x decreased by 15%. Emission rates for metals increased: 9 times for Zn, 7 times for Cr, 3 times for Pb and Mn, and 2 times for Fe and Al. HCl emissions increased by 60% but organic emissions (µg/m^3 of stack gases) of PAH and naphthalene dropped by 10%, and chlorobenzene dropped by 50%.

(iii) A second paper by Carrasco *et al.* (2002) also reported on emissions from the same Canadian cement plant (Lafarge's St. Constant facility) using whole tires as supplemental fuel with coal. They used the same raw data for velocity, temperature, and volumetric flow rate of gaseous effluents and pollutant concentrations at the kiln stack exit and clinker cooling unit stack, as in the earlier paper (Carrasco *et al.*, 1998). However, in this second paper they chose to report the amount of pollutants emitted to the atmosphere through the stacks per kilogram of clinker produced. For gaseous emissions normalized to clinker production they reported that CO increased by 37%, SO_2 by 24% and NO_x decreased by 11%. Emission rates for metals normalized to clinker production showed increases of 487% for Zn, 339% for Cr, 127% for Pb, 100% for Mn, 4% for Cu, 61% for Fe, and 33% for Al, whereas Hg decreased by 22%: overall metals increased by 82%. HCl emissions normalized to clinker production increased by 48%, whereas organic emissions decreased with PAH dropping by 14%, naphthalene by 8%, chlorobenzene by 37%, and dioxins and furans by 45%. The results presented in this second paper are identical to those in the first paper – the apparent difference in the numbers is because in this second paper emissions were normalized to clinker production. Needless to say, although concentrations of certain pollutants increased when tires were burned, the conclusion was the same as before; namely; emissions and maximum annual concentrations still complied with environmental standards by a wide margin. In short, the two papers reported the same results from the same study.

(iv) Long residence times and high operating temperatures of cement kilns provide an ideal environment to burn tires as supplemental fuel. The test results reviewed indicate that emissions are not adversely affected, but in many cases improve when burning tires or TDF (Clark *et al.*, 1991).

(v) Gaseous emissions were mostly unaffected, with significant reductions in NO_x and SO_x concentrations. Metal emissions do not appear to have any relationship with the fuel substitution practice. Emissions of even the most volatile elements in tires (Pb and Zn) were not increased, which were partially attributed to the fabric filter. Emissions of trace organics were essentially unaffected by co-firing tires, confirming the highly efficient combustion conditions in the kiln. (Guigliano, *et al.*, 1995).

(vi) A report from the IEA Clean Coal Centre (Smith, 2003) states that adding tires to the fuel in a cement kiln can achieve 30-50% reduction in NO_x emissions, but reductions in excess of 60% can be achieved with staged combustion or re-burn. In most cases alternative fuels have little effect on other emissions, although there have been cases of a substantial reduction in mercury emissions with co-combustion of tires. Most particulate matter, including non volatile trace elements, captured by fabric filters or ESP, is incorporated in the clinker. Organic compounds are completely oxidized in the main burning zone where high flame temperatures exist, although the halogen content should be monitored to avoid formation of dioxins and furans.

(vii) The UK Health Protection Agency (HPA), issued a recent position statement (UK Department of Health, 2004) asserting that cement kilns, if well managed and maintained, are efficient and effective processes for burning substitute fuels. Even though changes in emissions do occur they are modest and site specific, hence there will be little change in air pollution levels. Furthermore, the UK HPA is unaware of any evidence that burning alternative fuels has caused adverse health effects.

4.2.2 Review of Consultants Reports

RRFB Nova Scotia commissioned Conestoga-Rovers and Associates to assess the potential air quality impacts of using scrap tires as a supplementary fuel at Lafarge's Brookfield cement plant. This independent report (Reusing, 2007) was part of RRFB Nova Scotia's due diligence in evaluating the Lafarge proposal to collect and process all scrap tires generated in the province. The report was peered-reviewed by GlobalTox Consultants International (Brecher, 2007). Both reports are available at http://www.rrfb.com/../pdfs/technical%20report.pdf.

Conestoga-Rovers and Associates reviewed 11 reports, a 2005 stack testing report from Lafarge giving air emissions from the Brookfield facility (Air Testing Services Inc., 2005), and conducted air dispersion modeling based on the emission data. Their 5 major conclusions relating co-combusting whole scrap tires in cement kilns are as follows.

- Zinc emissions may increase because zinc oxide is added to tires as part of the rubber vulcanization. Nevertheless, they conclude that typical cement kiln emission control systems are able to remove particulate and associated increased zinc emissions and, therefore, will still comply with applicable air quality standards. This is consistent with the findings of Carrasco *et al.* (1998 and 2002).
- Co-combusting coal with whole tires injected mid-kiln can cause higher emissions of carbon monoxide (CO), however the increased emissions will comply with applicable air quality standards. This is consistent with observation No. 4 (section 4.2.1) and the findings of Carrasco *et al.* (1998 and 2002).
- Nitrogen oxides (NOx) emissions are reduced by injecting whole tires mid-kiln because of decreased thermal load and lower peak flame temperatures. NOx is one of the highest emission compounds from cement kilns and TDF provides a significant benefit in terms of emissions reductions. This is consistent with observation No. 2 (section 4.2.1), and the findings of Carrasco *et al.* (1998 and 2002), Guigliano *et al.* (1995), and Smith (2003).
- The combination of high temperature, long residence time and turbulent air flow in a cement kiln promotes complete combustion of organic compounds and results in low emissions of volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs) and dioxins and furans. The literature reports only small variations of emissions of organic compounds when using TDF in a cement kiln and emissions always comply with applicable air quality standards. This is consistent with the findings of Carrasco *et al.* (1998 and 2002) and Clark *et al.* (1991). For the case of dioxins and furans, the

assertion that emissions always comply with applicable air quality standards is consistent with the findings of Abad *et al.* (2004). However, there is an enormous variation in reported emission data for dioxins and furans (see Section 4.2.3 and conclusion No. X in section 6.1).

- Compounds such as SO_2 and acid gases report minor variations in emissions with TDF co-combustion and are in compliance with air quality standards. This is not consistent with the findings of Guigliano *et al.* (1995) who report significant reductions in SO_x, nor that of Carrasco *et al.* (1998 and 2002), who report increases of SO_x. Nevertheless, even where increases were reported SO_x were in compliance with air quality standards.

All the conclusions of the report by Conestoga-Rovers and Associates are consistent with the findings of the UK Department of Health (2004) as summarized in the statement:

"It is CRA's opinion that the use of TDF in the Brookfield kiln will not have an adverse effect on ambient air quality and may provide many environmental and community benefits."

4.2.3 Dioxins and Furans

Dioxins consist of a family of compounds known as polychlorinated dibenzo-p-dioxins (PCDD); furans are polychlorinated dibenzo furans (PCDF). They have similar structures; the aromatic molecules in dioxins are bridged by two oxygen atoms, whereas the furans have only one oxygen bridge.

The formation of dioxins and furans has been the subject of numerous studies in the past 20 years; studies relating to cement kilns are well summarized in a report on the cement industry by Environment Canada (2004). The compounds are formed by the reaction of organic compounds with a chloride species in the presence of oxygen. Any combustion process has the potential to form these polychlorinated oxygenated aromatics because of the presence of oxygen and chlorides, not only in the fuel, but also in the material being processed.

Some characteristics of PCDD/F formation are as follows:

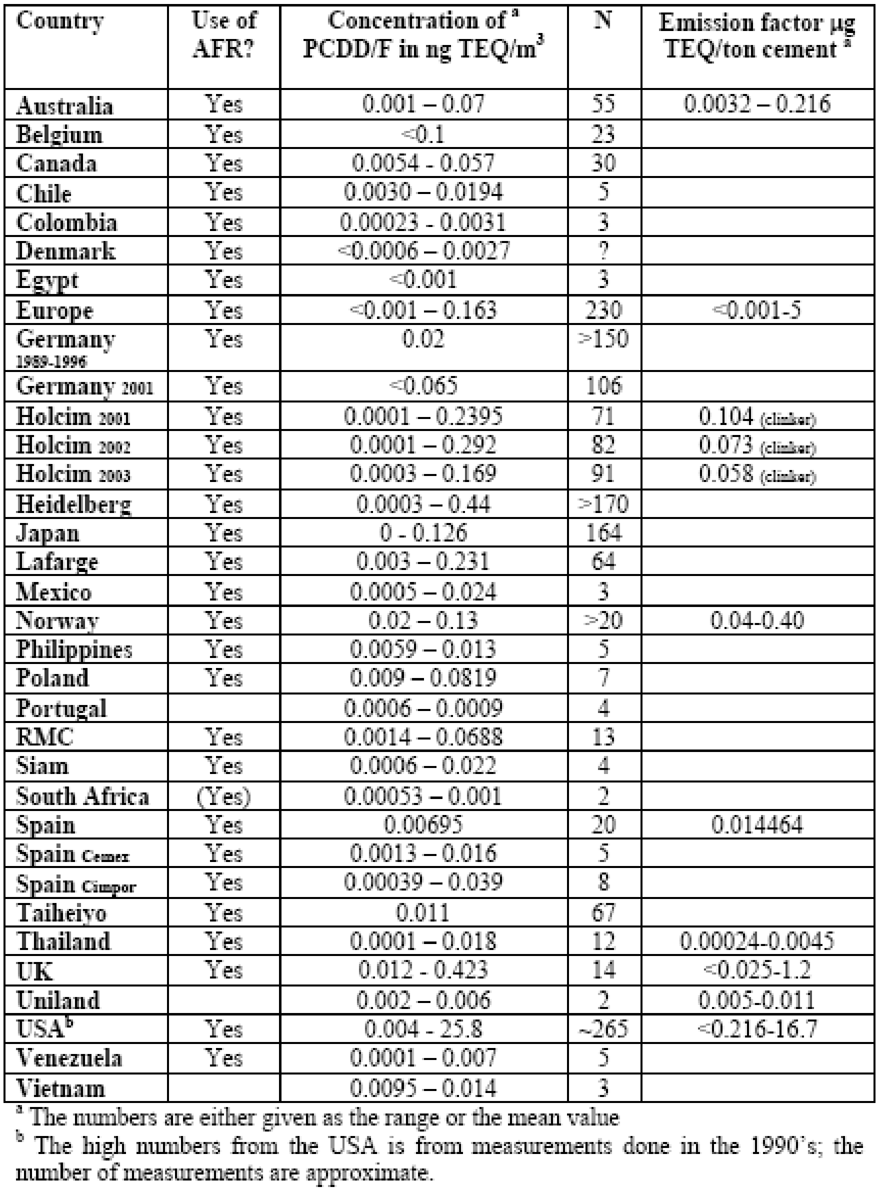
1. PCDD/Fs are formed from gas-phase precursors either by gas-phase homogeneous reactions (minor pathway) or gas-solid condensation reactions (major pathway).
2. Precursor reactants can be formed at temperatures up to 800°C which can lead to the formation of PCDD/F at these high temperatures; however at temperatures over about 935°C, PCDD/F's decompose rapidly.
3. Reaction of chlorine, oxygen and hydrocarbons will form PCDD/F. Zevenhoven and Kilpinen (2005) present data showing that the formation reaction rate has a Gaussian distribution, with a maximum at 400°C, and essentially no reaction below 250°C or above 500°C.
4. The presence of trace elements, especially Cu and Pb can catalyze the dioxin formation reaction. On the other hand, some elements such as sulphur and calcium inhibit the dioxin formation reactions.
5. Under pyrolytic conditions, increasing O_2 promotes PCDD/F formation.
6. PCDD/F compounds can be present in the feed itself and contribute to the emissions measured.

A fairly comprehensive study of the thermodynamics of dioxins and furans (50-60 species) formation has been reported by Yazawa *et al.* (1999). They found that these toxins are formed below 400°C. They also investigated the effect of chlorine and oxygen. Both high temperatures and high oxygen (O/Cl > 1) levels "result in drastic decomposition of PCDD/Fs." As expected, the chlorine content of the dioxins/furans varies with the available chlorine content in the flue gases. It was pointed out that these are only theoretical equilibrium calculations; formation mechanisms are also governed by the kinetics of the reactions.

Emissions of Dioxins and/or Furans

A extensive compilation of data on PCDD/F emissions for cement kilns has been prepared by Karstensen (2004). The summary table from the report is reproduced here as Table 12 and represents about 34 operations with about 1,700 pieces of data. Note that these data include all modes of operation, with and without alternate fuel and different types of control devices.

Table 12: Summary of PCDD/F Measurement Data[10]



Country	Use of AFR?	Concentration of [a] PCDD/F in ng TEQ/m^3	N	Emission factor µg TEQ/ton cement [a]
Australia	Yes	0.001 – 0.07	55	0.0032 – 0.216
Belgium	Yes	<0.1	23	
Canada	Yes	0.0054 - 0.057	30	
Chile	Yes	0.0030 – 0.0194	5	
Colombia	Yes	0.00023 - 0.0031	3	
Denmark	Yes	<0.0006 – 0.0027	?	
Egypt	Yes	<0.001	3	
Europe	Yes	<0.001 – 0.163	230	<0.001-5
Germany 1989-1996	Yes	0.02	>150	
Germany 2001	Yes	<0.065	106	
Holcim 2001	Yes	0.0001 – 0.2395	71	0.104 (clinker)
Holcim 2002	Yes	0.0001 – 0.292	82	0.073 (clinker)
Holcim 2003	Yes	0.0003 – 0.169	91	0.058 (clinker)
Heidelberg	Yes	0.0003 – 0.44	>170	
Japan	Yes	0 - 0.126	164	
Lafarge	Yes	0.003 – 0.231	64	
Mexico	Yes	0.0005 – 0.024	3	
Norway	Yes	0.02 – 0.13	>20	0.04-0.40
Philippines	Yes	0.0059 – 0.013	5	
Poland	Yes	0.009 – 0.0819	7	
Portugal		0.0006 – 0.0009	4	
RMC	Yes	0.0014 – 0.0688	13	
Siam	Yes	0.0006 – 0.022	4	
South Africa	(Yes)	0.00053 – 0.001	2	
Spain	Yes	0.00695	20	0.014464
Spain Cemex	Yes	0.0013 – 0.016	5	
Spain Cimpor	Yes	0.00039 – 0.039	8	
Taiheiyo	Yes	0.011	67	
Thailand	Yes	0.0001 – 0.018	12	0.00024-0.0045
UK	Yes	0.012 - 0.423	14	<0.025-1.2
Uniland		0.002 – 0.006	2	0.005-0.011
USA[b]	Yes	0.004 - 25.8	~265	<0.216-16.7
Venezuela	Yes	0.0001 – 0.007	5	
Vietnam		0.0095 – 0.014	3	

[a] The numbers are either given as the range or the mean value

[b] The high numbers from the USA is from measurements done in the 1990's; the number of measurements are approximate.

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[10] Table 4-15 from Environment Canada (2004). Original source, Table 26 of Karstensen (2004).

To summarize:

- Emission values ranged from a low of 0.1 pg I-TEG/Rm^3 to a high of 440. (The one value of 25,800 for the US in the 1990s was not considered as representative).
- The average low value was 3 (range 0.1 to 9) pg I-TEG/Rm^3; and
- The average high value was 99 (range 1 to 440) pg I-TEG/Rm^3.

Environment Canada (2004) has also summarized this and other data relating to PCDD/F emissions in cement kilns. Some additional data were found relating to PCDD/F emissions in kilns; these are presented in Table 13. To convert data on different bases into pg/Rm^3, the following conversion factors were used:

Rm^3 (25°C, 101.3 kPa, 11% O_2)/tonne clinker	2,400
GJ fuel/tonne clinker	4.7
tonne clinker/tonne feed	0.92

Table 13: Some Literature Values of Dioxin/Furan Emissions in Cement Kilns

Reference	**pg (I-TEQ) / Rm^3**	**Comments**
EIPPC (2001)	100–500	1-yr avg, 10% O_2
EPA emission factor (1994)	112	
Air Testing Services (2004) (Brookfield)	21.5 17.2	baseline with supplemental fuel
NPRI (Brookfield, 2002-05)	120	
NPRI (St Constant, 2005)	226	estimate only
NPRI (St Constant, 2004)	219	estimate only

Some data were found which directly compared the emissions with and without tires, and some data on kilns burning both tires and primary fuel (usually coal). These data are presented in Table 14.

Table 14: PCDD/F Emission Levels in Cement Kilns Burning Tires

Kiln	no tires, pg (I-TEQ)/Rm^3	with tires pg (I-TEQ)/Rm^3	Reference
Lafarge, Plant1, K1	—	11.3 (7 data)	Karstensen (2004)
Lafarge, Plant1, K2	—	4.0 (7data)	Karstensen (2004).
Lafarge, Plant2, K3	—	57.0 (3 data)	Karstensen (2004).
Lafarge, Plant6	—	34.5 (2 data)	Karstensen (2004).
Thailand, Kiln 1	10.5	2.7 (3 data)	Karstensen (2004).
Thailand, Kiln 2	2.9	0.8 (3 data)	Karstensen (2004).
Heidelberg Cement Co	16.0 (8 kilns)	9.0 (9 data)	Karstensen (2004).
European Kilns	—	16.6 (5 data)	Karstensen (2004).
Australian Cement Indust	4.3–250	8.7–280	Envir Australia (2002)
St. Constant, Quebec	1000.	400.0	Carrasco et al. (2002)
Calaveras, CA	—	6.3	Federal Reg (1998)

Many kilns add alternate fuel; the fuel varies considerably. Major types are municipal solid waste, construction wastes, hazardous waste, used oil and tires. Since the present study is concerned with tires, the search was limited to those kilns using tires as the alternate fuel.

The major point to be noted is that the range in emission factors is very large. The difference between the average low values and average high values is about 2 orders of magnitude. As pointed out previously, the formation of dioxins/furans is extremely complex and depends on a multitude of equilibrium and kinetic relationships, and, as well, on the design and operation of the kiln itself. Thus, the resulting variation in emission levels is not unexpected.

Pyrolysis

The destruction of a tire at high temperature involves its decomposition into various organic species. In the presence of oxygen, combustion of these species takes place, converting the hydrocarbons into mostly CO_2 and water. In a zero or very low oxygen environment, where the oxygen concentration is too low to support combustion, this decomposition is known as pyrolysis, or "destructive distillation" and occurs at elevated temperatures, typically between 400 and 800°C. Such conditions might occur in the kiln during an upset, for example, if the main air supply for combustion is interrupted. Thus it is instructive to summarize the emissions from this process to determine their effect on overall emissions from the kiln.

The products of pyrolysis are:

1. a solid char;
2. a liquid known as pyrolysis oil; and
3. a gas.

A report on the environment effects of the process was prepared for the California Integrated Waste Management Board (1995). Their results showed that at the higher temperatures of the cement kiln, the products from the tire would be about 30% char, 40% oil and 30% gas. The gas contains the light compounds mainly H_2 (about 20%), methane (35%), C_2 (20%), C_3, C_4 (13%), and the rest CO. CO_2, and N_2. The liquid or "pyrolysis oil" has a range of properties similar to No. 2 to No. 6 fuel oil and contains a multitude of organic compounds. The solid material is mostly carbon (85%) and contains the ash components.

If a process upset occurs, the effect on the gaseous emissions of the tire is entirely dependent on the oxygen concentration. If there is sufficient oxygen present, then combustion of any organic material would take place. Specifically at Brookfield, a power outage would shut down the fuel system; however, in this case, there is enough natural draft to ensure an adequate oxygen level in the kiln. In addition, a standby diesel engine keeps the kiln rotating.

In the case of insufficient oxygen present for combustion of the pyrolysis products, the gas would be discharged to the atmosphere, and as well, most of the oil either in the form of vapour or even mist. It is difficult to postulate what effect this will have because of not knowing what happens in the kiln to the pyrolysis components which are mostly hydrogen, methane, and heavier hydrocarbons. If this problem is judged severe enough (it is assumed that only the one tire (~10 kg) has been fed to the kiln at upset conditions), then one possible means of control would be to divert the exhaust gases through a flare stack to ensure complete combustion of the pyrolysis products.

4.2.4 Achievable Performance Levels and Health Effects of Pollutant Emissions

Environment Canada (2004) prepared a draft document suggesting achievable performance levels for pollutant emissions from cement kilns. These levels are summarized in Table 15 and were arrived at based on a review of standards from Europe, the US, Canada and various Canadian jurisdictions, as well as best available technology. The proposed long-term goal for the emission standard of dioxins/furans by Environment Canada is 32 pg/Rm^3 stack gas, (equivalent to about 80 ng/tonne of clinker) although they have stated that “an achievable performance for PCDD/F is 0.1 ng (100 pg) I-TEQ/Rm^3 (see Appendix A for an explanation of I-TEQ)”. Most countries have adopted the 100 pg I-TEQ/Rm^3 as a standard with which to comply.

Table 15: Achievable Performance Levels for Cement Kilns

(Adapted from: Environment Canada, 2004)

Pollutant	Emission Concentration	Emission Factor
Total particulate matter (PM)	< 15 mg/Rm^3	<0.04 kg/t clinker
Nitrogen oxides (NO_x)	< 420 mg/Rm^3 30-day average	<1.0 kg/t clinker 30-day average
Sulphur oxides (SO_x)	< 300 mg/Rm^3 30-day average	<0.7 kg/t clinker
Total hydrocarbons (THC)	< 17 mg/Rm^3 (as carbon) 30-day average	<0.04 kg/t clinker as carbon
Hydrogen chloride (HCl)	< 25 mg/Rm^3	<0.06 kg/t clinker
Carbon monoxide (CO)	No level	-
Metals	**Class 1[11]:** < 1.5 mg/Rm^3 **Class 2[12]:** < 0.5 mg/Rm^3 **Class 3[13] :** < 0.05 mg/Rm^3	<3.6 g/t clinker <1.2 g/t clinker <0.12 g/t clinker
PCCD/F	0 <.1 ng I-TEQ/Rm^3	<0.24 µg/t clinker
Hexachlorobenzene (HCB)	long term goal is the Limit of Quantification 6 ng/Rm^3	14.4 µg/t clinker
Benzene	< 4 mg/Rm^3	<9.6 g/t clinker

The performance standards given in Table 15 can be used for compliance testing. To assess the impact on human health one needs to ensure that the ground level concentrations do not exceed agreed upon threshold limits.

The EPA has set National Ambient Air Quality Standards for six principal pollutants, referred to as "criteria" pollutants. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly, whereas secondary standards set limits to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation, and buildings. Table 16 lists these National Ambient Air Quality Standards.

For other pollutants there are established upper intake levels or Tolerable Daily Intakes (TDI). For PCCD/F a TDI of 2 pg I-TEQ/kg body weight/day has been suggested (Jones and Tinkler, 2006). The WHO has recommended TDI for many metals, HCB and many other chemicals. For example, the TDI for HCB and Cd is 0.17 and ~ 1 µg/kg body weight/day.

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[11] Class 1: combined mass of antimony, cadmium, copper, lead, manganese, vanadium, and zinc.

[12] Class 2: combined mass of arsenic, chromium, cobalt, nickel, selenium, and tellurium.

[13] Class 3: limit applies separately to mercury and thallium.

Table 16: National Ambient Air Quality Standards (EPA, 1990)

Pollutant	Primary Std.	Averaging times	Secondary Std.
Carbon Monoxide	9 ppm (10 mg/m^3)	8-h[14]	None
	35 ppm (40 mg/m^3)	1-h[1]	None
Lead	1.5 μg/m^3	Quarterly Average	
Nitrogen dioxide	0.053 ppm (100 μg/m^3)	Annual (Arith Mean)	
PM$_{10}$	Revoked[15]	Annual[2] (Arith Mean)	
	150 μg/m^3	24-h[16]	
PM$_{2.5}$	15.0 μg/m^3	Annual[17] (Arith Mean)	Same as primary
	35 μg/m^3	24-h[18]	
Ozone	0.08 ppm	8-h[19]	Same as primary
	0.12 ppm	1-h[20]	
Sulphur oxides	0.03 ppm		
	0.14 ppm	24-h[1]	
		3-h[1]	0.5 ppm (1300 g/m^3)

Table 17 shows major pollutant emissions from the Brookfield plant firing coal. Column 1 lists the major pollutants. The measured stack emissions (g/s) shown in column 2 are taken directly from the reported stack testing data (Air Testing Services Inc., 2005). The stack emissions (g/Rm^3) in column 3 are either calculated from the measured O_2 concentration and the dry stack gas volume, or taken directly from the reported test data. The values shown in column 4 are the achievable performance levels for cement kilns given in Table 15.

Comparison of columns 3 and 4 in Table 17 shows that stack emissions exceeded (*i.e.* emissions were greater than) the suggested achievable performance levels for PM, NO_x, SO_x and THC, but were better (*i.e.* emissions were less than) for all the other pollutants.

Conestoga-Rovers & Associates (Reusing, 2007) used the USEPA SCREEN3 air dispersion model to calculate a dispersion factor for emissions from the stack that could then be applied to the various emission rates. Their results predicted a maximum ground level concentration of 2.023 μg/m^3 for a 1 g/s emission rate at 950 m from the stack. Column 5 of Table 17 gives the calculated maximum ground level concentration of the measured pollutants based on the reported dispersion modelling. Columns 6 and 7 give the EPA national air quality standards or the WHO TDI levels for the various pollutants. Comparison between column 5 and, either column 6 or 7,

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[14] Not to be exceeded more than once per year.

[15] Due to a lack of evidence linking health problems to long-term exposure to coarse particle pollution, the agency revoked the annual PM$_{10}$ standard in 2006 (effective December 17, 2006).

[16] Not to be exceeded more than once per year on average over 3 years.

[17] To attain this standard, the 3-year average of the weighted annual mean PM$_{2.5}$ concentrations from single or multiple community-oriented monitors must not exceed 15.0 μg/m^3.

[18] To attain this standard, the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area must not exceed 35 μg/m^3 (effective December 17, 2006).

[19] To attain this standard, the 3-year average of the fourth-highest daily maximum 8-hour average ozone concentrations measured at each monitor within an area over each year must not exceed 0.08 ppm.

[20] The standard is attained when the expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is ≤ 1. However, as of June 15, 2005 EPA revoked the 1-hour ozone standard in all areas except the fourteen 8-hour ozone non-attainment Early Action Compact (EAC) Areas.

shows that in all cases maximum ground level pollutant concentrations were below accepted health standards.

Table 18 shows major pollutant emissions from the Brookfield plant firing coal and alternate fuel (waste roofing shingles). As before, stack emissions exceeded the suggested achievable performance levels for PM, NO_x, SO_x and THC, but were better for all the other pollutants. Likewise, in all cases maximum ground level pollutant concentrations were below accepted health standards.

Table 17: Emissions from the Brookfield plant (coal only)

Pollutant	**Stack Emissions**			**Ground Level**		
	Measured		Achievable	Calculated	Health Standards	
	g/s	g/Rm^3	g/Rm^3	µg/m^3	µg/m^3	µg/kg(bw)/day
PM	1.16	4.40E-02	1.50E-02	2.34	165	–
NOx	18.6	0.51	0.42	37.57	100	–
SOx	20.9	0.58	0.3	42.22	400	–
THC	0.76	2.10E-02	1.70E-02	1.54	–	–
HCl	0.121	5.20E-03	2.50E-02	0.244	–	–
CO	9.9	0.270	–	20.00	10,000	–
Metals, Class 1	2.07E-03	5.84E-05	1.50E-03	4.18E-03	–	–
Metals, Class 2	4.20E-04	1.18E-05	5.00E-04	8.48E-04	–	–
Metals, Class 3, Hg	1.89E-04	5.34E-06	5.00E-05	3.82E-04	–	–
Metals, Class 3, Th	3.30E-04	9.30E-06	5.00E-05	6.67E-04	–	–
PCDD/F	5.00E-10	2.15E-11	1.00E-10	1.01E-09	4.30E-06	2.00E-06
Hexachlorobenzene	0.00	0.00	6.00E-09	0.00E+00	0.37	0.17
Benzene	6.73E-02	2.91E-03	4.00E-03	0.136	–	–

Table 18: Emissions from the Brookfield plant (coal + alternate fuel)

Pollutant	**Stack Emissions**			**Ground Level**		
	Measured		Achievable	Calculated	Health Standards	
	g/s	g/Rm^3	g/Rm^3	µg/m^3	µg/m^3	µg/kg(bw)/day
PM	1.66	6.60E-02	1.50E-02	3.35	165	–
NOx	19.7	0.545	0.42	39.8	100	–
SOx	22.3	0.617	0.3	45.0	400	–
THC	1	2.77E-02	1.70E-02	2.02	–	–
HCl	0.218	9.19E-03	2.50E-02	0.44	–	–
CO	9.23	0.255	–	18.6	10,000	–
Metals, Class 1	6.70E-03	1.84E-04	1.50E-03	1.35E-02	–	–
Metals, Class 2	3.60E-03	9.83E-05	5.00E-04	7.27E-03	–	–
Metals, Class 3, Hg	1.95E-04	5.46E-06	5.00E-06	3.94E-04	–	–
Metals, Class 3, Th	3.72E-04	1.04E-05	5.00E-05	7.51E-04	–	–
PCDD/F	6.20E-10	2.60E-11	1.00E-10	1.25E-09	4.30E-06	2.00E-06
Hexachlorobenzene	0.00	0.00	6.00E-09	0.0	0.37	0.17
Benzene	7.49E-02	3.19E-03	4.00E-03	0.15	–	–

5.0 RISK MANAGEMENT FRAMEWORK FOR TDF APPLICATIONS

The purpose of this report section is to provide a risk-based framework for assessing and managing the risks associated with the use of tire-derived fuel (TDF) in industry. To provide a common understanding of terminology, a general discussion of hazard, risk, and the risk management process is first given. This is followed by a specific application of the risk management process to burning of TDF in a cement kiln.

5.1 General Considerations

The terms *hazard* and *risk* are often used interchangeably. This is unfortunate and potentially confusing because hazard and risk are not the same thing. Functional definitions (Wilson & McCutcheon, 2003) of *hazard* and *risk* are as follows:

> *Hazard:* The potential of a machine, equipment, process, material or physical factor in the working environment to cause harm to people, environment, assets or production.
>
> *Risk:* The possibility of injury, loss or environmental injury created by a hazard. The significance of risk is a function of the *probability* (or *likelihood*) of an unwanted incident and the *severity* of its consequence.

Risk therefore arises from hazards. This implies that thorough hazard identification is key to the effective management of risk; one cannot manage the risk arising from a hazard that has not been identified.

A functional definition (Wilson & McCutcheon, 2003) of *risk management* is as follows:

> *Risk Management:* The complete process of understanding risk, risk assessment, and decision making to ensure effective risk controls are in place and implemented. Risk management begins with actively identifying possible hazards leading to the ongoing management of those risks deemed to be acceptable.

Embodied in this definition of risk management is the cycle of risk analysis, which enables risk assessment, which in turn enables risk management (Bird & Germain, 1996). In essence, one must *analyze risk* (for probability and consequences), to be able to *assess risk* (with respect to acceptability), so as to ultimately *manage risk*. As previously mentioned, it is simply not possible to commence this cycle without first effectively identifying the hazards of concern.

This process of risk management is shown in Fig. 15, which represents best practice throughout the world, particularly for hazardous industries but spreading to others. Each step requires different activities to be conducted in differing formats. The result is a process that has been employed globally for the past two decades and is considered to be the best currently available (see for example, Crowl and Louvar, 2002). The various steps given in the generic framework shown in Fig. 15 are briefly explained below from a general perspective.

Planned Reviews - This is a management function in which reviews are conducted to provide the data needed to monitor operations or develop new project designs. This is essentially the database for an effective safety and loss management system. It would include incident investigations, insurance company reviews, regulatory activities (pressure vessel inspections, environmental reporting, asset renewal needs, changes to laws, code updates, *etc.*) – in addition to the regular data collected on business operations and maintenance activities. The objective in this step is to be proactive, so that gathering the data and doing trend analyses in conjunction with statistical analyses will keep a company out of difficulty.

Identification of Hazards - One of the outcomes of doing the above mandated reviews (as a management team and by paying attention to industry activities in general through trade associations and the news), will be the identification of hazards (or “concerns”). A company’s management team will receive the data and, in the judgment of the team, will determine what needs to be considered further by means of a risk analysis. There are a variety of tools available for hazard identification – for example, Hazard and Operability Study (HAZOP), What-If Analysis, Checklist, Fault Tree, *etc*.

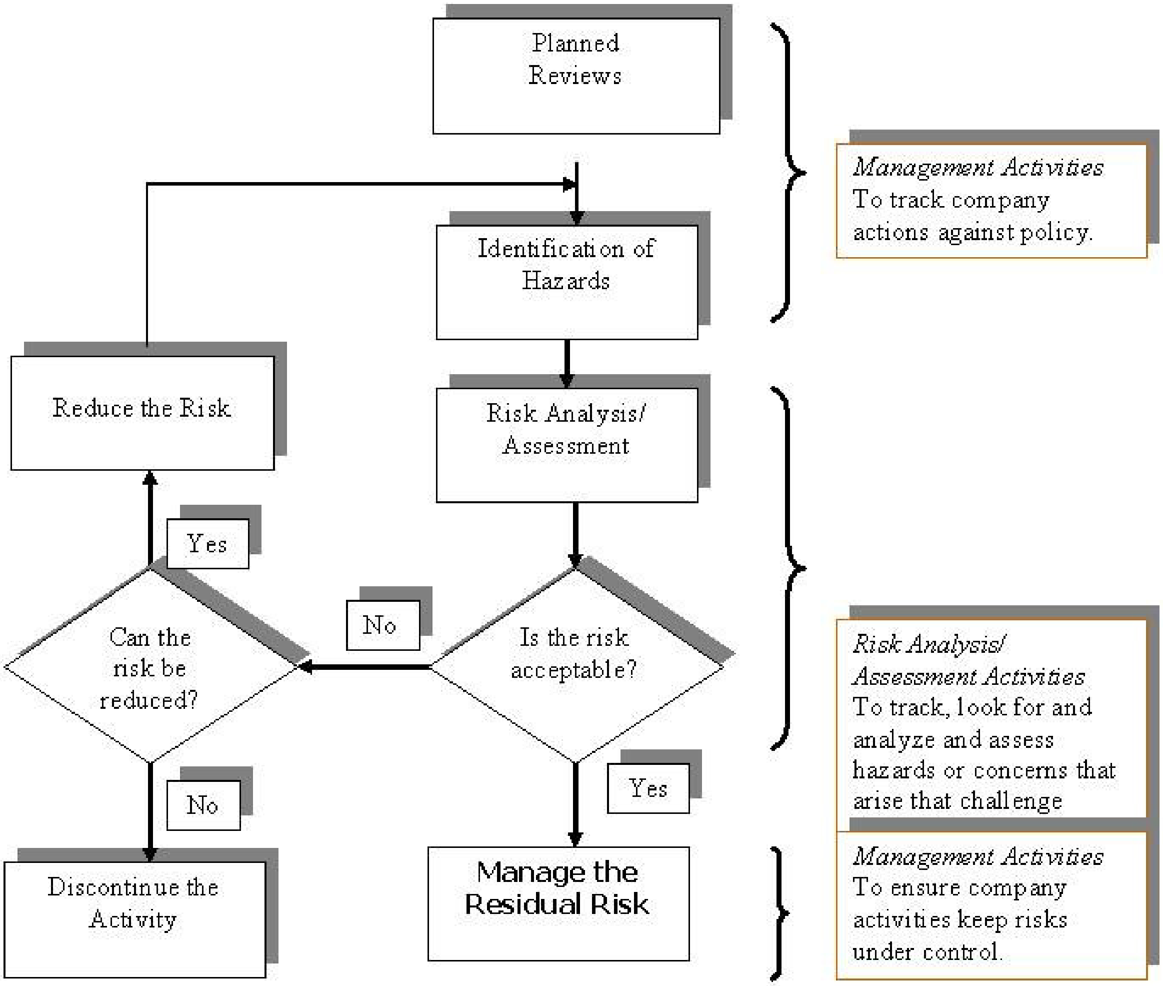

Figure 15: The risk management process

Risk Analysis/Assessment - Similarly, there are many tools available to help with risk analysis and assessment. Risk analysis involves gaining an understanding of the risk components – probability and consequences. Probability pertains to the failure of systems, humans, equipment, *etc*., and in many instances is readily quantifiable. Some data are available generically, but the most pertinent data are often found in a company's maintenance records, operational logs and incident investigation reports.

There also exist a number of methodologies to quantify the consequences of many of the hazards encountered in industrial practice, such as fires (thermal radiation and smoke), explosions (blast wave overpressures), toxic cloud dispersion, toxic exposures, lethality, noise, water pollution, *etc*. Once the probability and severity of consequences are known and the risk estimated, risk assessment is conducted to determine whether the risk is acceptable or not.

Is the Risk Acceptable? - Many company managements have developed a risk matrix describing what is a low-level risk (acceptable), medium-level risk (acceptable with certain conditions), and high-level risk (unacceptable). Such matrices clarify to employees what they must do and what is acceptable. The low-level risks are usually acceptable without any further management involvement or design additions. With respect to medium risk, management needs to be actively involved to ensure the risk is kept under control; it is worthwhile noting here that management's responsibilities come to the forefront as they (managers) are assuming responsibility for accepting the risk.

Manage the Residual Risk - Once a risk is determined to be acceptable, it must be managed. This is arguably the most important step in the process as responsibility has now been taken for assuming the risk and preventing any undesirable incident from occurring. A key tool employed in this stage is a management system appropriate for the risks being managed (*e.g.* health, occupational safety, process safety, equipment reliability, *etc.*). Safety management systems are recognized and accepted worldwide as best-practice methods for managing risk. They typically consist of 10 – 20 program elements (*e.g.* management of change) that must be carried out to manage the risks in an acceptable way. Once a risk is accepted, it does not go away; it is there waiting for an opportunity to happen unless the management system is actively monitoring company operations for concerns and taking proactive actions to correct potential problems.

Can the Risk be Reduced? - Often there are ways to reduce the risk once its level is determined to be unacceptable. The term *inherent safety* is used to imply methods which will eliminate or reduce the risk by tackling the underlying hazards themselves (*e.g.* by substitution of a less hazardous material; Khan and Amyotte, 2003). Additionally, further controls, management systems, protective features, and the like can be added to reduce the risk to an acceptable level.

Reduce the Risk - If the proposed risk reduction measures are viable, then the necessary changes must be made to equipment, procedures, hazardous inventories, *etc.* It is important to note that once a change is made, the risk management cycle is once again used to evaluate possible new hazards and risks. Changes in industrial processes often create additional potential problems that can unintentionally (and perhaps unknowingly) lead to increased operational risk.

Discontinue the Activity - A very important step is to recognize when the risk is too high. Management needs to be crystal clear on this and make the right decisions. Company values and objectives come into play at this stage – including the factors of lost profits, personal promotions, professional defeat, *etc.* Discontinuing an activity because the risk is unacceptable is a key decision because it says that a company will not do something that is unsafe, pollutes the environment, damages assets, risks business opportunities needlessly, or impacts the public's view of the company in a negative fashion. Also, company employees will be watching their managers' performance at this stage; employee support for management decisions on risk acceptance is essential.

5.2 Specific Considerations

The adoption of a risk management framework facilitates examination of the final three objectives (5-7) of the current study:

- To determine the technological and process changes necessary to use TDF as a supplementary fuel at the Brookfield Lafarge cement plant.

- To identify both process and technological options to mitigate any environmental or health impacts associated with the use of TDF as a supplementary fuel at the Brookfield Lafarge cement plant.
- To review the Management of Change (MOC) issues relating to potential hazards and safety that must be addressed using TDF as a supplementary fuel at the Brookfield Lafarge cement plant.

The first two items above relate to the *management of residual risk* and the *implementation of risk reduction measures* (Fig. 15). The last item on MOC is directly relevant to the *hazard identification* block in Fig. 15, and is therefore a logical starting point for analysis of the risk of burning TDF in a cement kiln.

Change is a given in any industrial operation today. Reasons for change include the need to keep up-to-date with current technology, the desire for more efficient production so as to enhance competitiveness, and the introduction of new laws and regulations. Whenever a change is made – whether large or small, permanent or temporary – it is essential to assess the possible impacts of the change. Management of Change (MOC) is a systematic method used to do accomplish this task; in essence, MOC follows the general procedure given in Fig. 15, where the identification of hazards is prompted by the introduction of a change in the workplace.

In the present study, the burning of tires in a cement kiln clearly represents a change in the operating process. The displacement of coal by up to 20 % of its heating value with TDF is not a replacement-in-kind; a risk-based MOC protocol is therefore required to answer such fundamental questions as:

- What could go wrong?
- How likely is it to happen?
- How could it affect key receptors such as employees, the surrounding community, the environment, *etc.*?
- What can be done about the hazards and risks introduced by the change?

Physical Scope - The physical scope for risk management defines the boundaries of the analysis. With respect to the Lafarge Brookfield plant, the physical scope extends from the cement kiln itself into the surrounding environment (both natural and human) that could reasonably be expected to experience an impact from changes made to the fuel-burning process in the kiln.

Analytical Scope - The analytical scope for risk management defines the nature of the hazards to be identified and the resulting risks that must be assessed. Establishing the analytical scope addresses the harm to be evaluated in terms of the broad categories of people, environment, assets, and production. The mandate for the present study has set the analytical scope as health and environmental impacts. Given the previously described physical scope, these impacts relate to both on-site and off-site locations. Asset integrity issues (*e.g.* equipment damage) and production losses (*i.e.* business interruption), although obviously important to Lafarge, are outside the scope of the current analysis. Similarly, the analysis does not include occupational safety concerns associated with kiln modifications to accommodate TDF usage.

Hazard Identification - Within the established physical and analytical scopes, the primary focus of the study team has been on stack emissions – more specifically, changes in emission species due to the burning of whole tires in a cement kiln. Other sections of the current report have described the percentage changes in stack components such as CO, SO_2, and NO_x (among others). On the basis of the comprehensive literature review conducted, as well as available plant data, there is reasonable confidence in predicting these changes caused by TDF usage in cement kilns.

What is less certain is the impact of TDF on the formation of dioxins and furans and subsequent release of these species to the natural and human environments. As previously documented in the current report, there is a large range in reported dioxin/furan emissions from cement kilns worldwide. Further, dioxin/furan emission rates appear to be kiln-specific and thus cannot be generalized without accompanying uncertainty.

While the risk from dioxins and furans in the present application remains to be discussed, it is indisputable that these chemicals have the potential to cause harm to people and the environment. Like other materials involved in cement production, they are therefore hazards. The reasons for identifying dioxins and furans as *hazards of primary concern* with respect to burning tires in a cement kiln are twofold:

1. The aforementioned uncertainty in reported dioxin/furan emission rates in the literature; and
2. The significant concern (among others) expressed by local stakeholders toward dioxin/furan emissions from the Brookfield plant.

Further support for focusing attention on dioxins and furans can be found in the work of Cook and Kemm (2004). They conducted a Health Impact Assessment (HIA) for the case of a cement plant in England that had applied for a permit to use TDF (chopped tires) as a partial replacement for coal as kiln fuel. Their study broadly concluded that allowing this proposal to proceed would be unlikely to cause adverse impacts; Table 19 gives the likely emission impacts.

Table 19: Likely health impacts from emissions if tire burning permitted
(Cook and Kemm, 2004).

Intermediate Factor	Likely Impact
Trace metals	Increase in zinc, small decrease in most other trace metals. No impact on health or small benefit.
Dioxins	Change unlikely – needs to be carefully monitored. If no change – no health impact.
Particulates	Possibility of some increase in particulates. Impact depends on the size distribution of the particulates. Observable health changes unlikely.
Oxides of nitrogen	Possible reduction – small health benefit.
Sulphur dioxide	No change – no health benefit.
Carbon monoxide	Slight reduction.

The likely impact listed in Table 19 for dioxins is the least certain of all impacts and is the only one to mention the need for careful monitoring. In isolation, this would not necessarily be compelling evidence to focus attention on dioxins and furans as significant hazards of concern. The impacts listed in Table 19 are, however, consistent with the general trend observed in the TDF literature that dioxin/furan emission data have the widest range in reported values, and hence the greatest potential for uncertainty in extrapolating from the general case to a site-specific application.

The discussion now shifts to a consideration of the risk arising from the identified hazards (dioxins and furans). The basic framework which follows is intended as a roadmap indicating the data requirements for a complete assessment of risk within the defined physical and analytical scopes.

5.2.1 Risk Analysis – Likelihood

The likelihood of dioxin/furan formation and release is directly related to the extent that the *Three T's* of cement kiln operation are satisfied. As often quoted in the literature, complete fuel combustion and low pollutant emissions from cement kilns are dependent on high *temperature*, long residence *time*, and *turbulent* air flow. As specifically noted in the report by Conestoga-Rovers & Associates (Reusing, 2007), any claim of low dioxin/furan emissions rests squarely on the assumption of proper kiln operation with respect to these three parameters. This point has also been emphasized in a report by the US EPA (1991) in which the following statement is made: *High temperatures, long residence times, and an adequate supply of oxygen assure complete burnout of organics, which minimizes the formation of dioxins and furans.* Additionally, previous sections of the current report have addressed the issue of dioxin/furan formation from these fundamental perspectives.

Likelihood analysis for dioxin/furan formation and release should therefore focus on scenarios in which:

- an undesirable temperature window is attained;
- residence times at desirable high temperatures are shortened; and
- low-oxygen, pyrolysis-supporting atmospheres are facilitated.

These scenarios should be developed specifically for the Lafarge Brookfield site so that generalizations from literature reports and database emission rates do not have to be employed other than in a guidance capacity. Historical data from the Brookfield plant, such as a record of power outages and process upsets, would be beneficial for the purpose of estimating an annual occurrence of credible scenarios leading to enhanced dioxin/furan formation.

5.2.2 Risk Analysis – Consequence Severity

The severity of the consequences of dioxin/furan formation and release will depend on a number of factors, including:

- the pollutant concentrations leaving the stack;
- the concentrations reaching key receptors (natural and human) both on-site and off-site; and
- the persistence of the contaminants in the natural environment (air, water and soil).

Each of these factors will in turn depend on a number of parameters which are unique to the particular application. For example, estimation of pollutant concentrations extending beyond the point of emission will require dispersion modeling with Brookfield and vicinity meteorological data (again, an example of the requirement for the risk analysis to be site-specific).

5.2.3 Risk Assessment – Acceptability

Assessment of whether the risk of dioxin/furan formation and release is acceptable will be complex and potentially controversial. This is to be expected when one considers the inherent data uncertainties and the multitude of stakeholders involved. Further, without actual pilot testing and emission monitoring at the Brookfield site using TDF, estimation of pollutant concentrations at point-of-emission will necessitate expert judgment involving emission data from other cement plants burning TDF and the Brookfield plant burning supplemental fuels other than TDF. This is unavoidable given that the variability in feed materials and process parameters makes it unfeasible to predict the level of dioxin/furan formation.

What can be facilitated by the above framework for likelihood and severity analysis is the decision whether to proceed to the pilot test stage and institute a rigorous emission monitoring program at the Lafarge Brookfield plant. One could make the argument that such an analysis is not needed to proceed to the trial stage given that other jurisdictions (provinces, states, countries) have permitted the burning of tires in cement kilns. However, the extent of the risk assessment conducted in these other jurisdictions is not known in detail sufficient for comparison with the process shown in Fig. 15 and employed in the present study.

Simply put, the overwhelming consensus in the literature is that when a cement kiln is operating properly, dioxin and furan formation is not an issue. What happens when a cement kiln is *not* operating properly has not been analyzed to the extent that the present study can recommend bypassing the risk analysis stages for likelihood and severity of consequences. Ultimately, acceptance of risk for dioxin/furan formation will depend on reasonable assurance of meeting the concentration targets previously described in the current report.

5.2.4 Risk Reduction Measures and Management of Residual Risk

Risk reduction measures are those means employed to reduce the risk to an acceptable level (should this in fact be possible). Implementation of a risk reduction measure will necessitate a return to the hazard identification step of Fig. 15 to ensure that new hazards have not been unintentionally introduced. Even if the risk is initially deemed to be acceptable, there is still a need to manage the residual risk. This will likely be accomplished by a combination of risk reduction measures, process monitoring, and a management system appropriate for the hazards and risks involved.

In general terms, a hierarchy of controls (Amyotte *et al*., 2006) is recommended for reducing risk by considering, in order of decreasing effectiveness:

- Inherent safety (elimination, minimization, substitution, moderation, and simplification),
- Passive engineered (add-on) safety,
- Active engineered (add-on) safety, and
- Procedural (administrative) safety.

Further general guidance can be found in the report by Environment Canada (2004) which recommends the following measures to benefit process efficiency and minimize pollutant releases from cement manufacturing facilities:

- Energy efficient process equipment, kiln drives, fans, and other electric equipment,
- Process and combustion control optimization with automated control systems to maintain stable kiln operation,
- Chlorine, sulphur and metals limits on wastes received for firing as supplementary fuels (as directed for the Lafarge Bath plant in MOE, 2006a),
- Maintaining quality control assurance of wastes received for firing as supplementary fuels,

- Waste introduction after kilns reach operating temperatures with primary fuels,
- Avoiding firing certain wastes in the preheater or precalciner burner to avoid incomplete burnout of organic compounds and unintentional emissions of toxic organic substances, and
- Maximizing the recycling of cement kiln dust and/or developing commercial markets to minimize waste quantities.

There are several control options which can be effective in lowering the emissions of dioxin-type compounds, some of which are discussed by Grossman (2003):

- **Temperature Control:** The best control of dioxins is to avoid their formation in the first place. Considering the sensitivity of the rate of dioxin/furan formation to temperature, it is important to prevent time-temperature situations which favour the formation reactions. In general, as noted in section 4.2.3, it is important for the gases to spend as little time as possible through the range of 250 – 500°C. Likely this is kiln-specific because of the multitude of factors involved.

- **Raw Materials:** It is possible that something in the raw cement feed materials will provide necessary ingredients for dioxin to form. Should emission testing indicate a major problem, one should look at the cement rock itself for possible dioxin/furan precursors (dioxins are only formed post-combustion) such as organic material, high chloride content, metals which can act as catalysts, *etc*.

- **Upsets:** In any industrial process, upsets do occur. Unfortunately, there is no documentation as to what consequence these upsets have on dioxin formation and emission levels as there are so many variables involved. The best control measure in upset situations is to ensure that there is an adequate supply of air to any organic material in the kiln. For example, in a power interruption, even though the primary air supply is shut off, there should still be a natural draft which would likely provide enough O_2 for a tire to be completely combusted.

- **Quenching:** A process known as "Thermoselect" developed in Locarno, Switzerland, controls the exit pyrolysis gas by use of a water jet to cool the gas from 2000°C to 95°C instantaneously. "The rapid cooling prevents the formation of dioxins and furans by dramatically reducing the residence time of the synthesis gas at high temperatures." (Calaminus and Stahlberg, 1998).

- Presently at Brookfield, water quenching of the exhaust gases to 350°C is part of the normal procedure prior to entering the ESP. During an upset, it may be necessary to cool the gases more quickly to shorten the time spent in the dioxin/furan formation zone. Production of wet cement kiln dust by the use of a wet scrubber is fraught with major problems; thus this technique should only be considered as an emergency measure.

- **Flare Stack:** With sufficient air, dioxins are destroyed above 500°C. A possible option during an upset would be diversion of the kiln gases to a flare if it were necessary. This is primarily dependent on the oxygen concentration in the kiln during upset. At this point, it is impossible to say whether this option would either be effective or necessary.

One can clearly see the Environment Canada (2004) recommendations and the hierarchy of controls (Amyotte *et al*., 2006) reflected in the list immediately above. The more effective risk reduction measures are those aimed at inhibiting the formation of dioxins and furans by eliminating or minimizing the conditions that favour their creation (thus addressing the likelihood component of risk). In any loss-producing scenario it is more desirable to take preventive measures than to mitigate consequence severity.

Added to the list above would be an emergency action plan designed to deal specifically with process upsets and the possible generation of dioxins and furans. This is in addition to any hardware devices that might be deemed necessary to manage residual risk. Given that the nature of the risk is more chronic than acute, emissions testing and continuous monitoring are considered to be essential risk reduction measures. The permitting of the Lafarge Bath cement plant in Ontario (MOE, 2006a & 2006b) might provide helpful guidance in this regard.

6.0 Conclusions

The major conclusions that can be drawn from this report are summarized as follows.

1. In 2005, 59.3% of all tires (on a weight basis) in the US were used as tire derived fuel (TDF), whereas in Canada in 2003/4, only 20% of all scrap tires were used as TDF.
2. Most TDF in Canada is used as a supplemental fuel in cement kilns where whole tires can be directly injected into the kiln.
3. Potential industrial applications within Nova Scotia that could utilize TDF are pulp and paper mills and the Point Aconi generating station. However, they could not utilizedwhole used tires and so some preprocessing (de-wiring and/or shredding) would be needed.
4. The only industry within Nova Scotia that could utilize whole used tires is Lafarge's Cement plant at Brookfield.
5. From a life-cycle perspective, fuel substitution is the least environmentally harmful means of recovering the energy content of used tires. Implicit in this statement is the assumption that emissions from facilities using TDF are no more harmful to the environment and human health than those resulting from conventional fuels such as coal.
6. Results from the cited LCA do not specifically evaluate quantitative life cycle effects of using tires as a supplemental fuel source at the Brookfield Lafarge plant, although they do indicate the expected trends.
7. There is quite a large variation in all the emission data.
8. It appears that in the case of NO_x, there is a definite trend for this pollutant to decrease when tires are used as a supplemental fuel. This observation has been made by several researchers (average of 40% decrease; $\sigma = 20\%$).
9. The effect of burning tires (1% S) on the SO_2 emission does not seem to correlate; most of the SO_2 would come from the ore and the coal since the tires not only have relatively low sulphur content, but also replace only about 20% of the fuel.
10. CO emissions in most cases are higher (average 35% higher, $\sigma = 76\%$). This would indicate that the tires produce a fuel-rich zone as they undergo pyrolysis leading to a more incomplete combustion and a lower flame temperature in the kiln (consistent with the lower NO_x emissions).

11. The formation and destruction, and as a result, the emission rate of dioxins/furans is dependent on many factors: temperature-time profiles, composition of the fuel, composition of the raw materials themselves and gas composition. Unfortunately, there is no means of quantifying these effects and thus, it appears that the emission rates are, at least for dioxins/furans, quite kiln-specific.

12. Emissions for baseline operation of kilns (without tires added) have a very substantial range from 1 to about 400 pg (I-TEQ)/Rm^3 stack gas. At this point, because of this large variability, it is impossible to say what effect the burning of tires in the kiln would have on the formation and emission of dioxins/furans. Whatever effect there is, it is doubtful that substitution of tires for 20% of the total fuel input would change emission levels in a statistically significant manner relative to the other major parameters which are process and kiln related.

13. At Brookfield, the average dioxin/furan emission rate measured by Air Testing Services in 2004 was 21.3 pg (I-TEQ)/Rm^3 when firing coal only and 17.3 pg (I-TEQ)/Rm^3 when firing coal and supplemental fuel (waste roofing shingles). The emission rate reported over the years 2002-05 by NPRI was about 120 pg (I-TEQ)/Rm^3. To put this in context, cement kiln data from the US and other European sources show variations in emissions from a low average of 6 to the high average of 99 pg (I-TEQ)/Rm^3. A value of 100 pg (I-TEQ)/Rm^3 is considered a reasonable goal at the present time. Assuming that the recent measured value is the more indicative of present-day practice, Brookfield is already in compliance with the proposed standard of 32 pg I-TEQ/Rm^3.

14. Our review of literature and test reports appears to support the conclusion that use of whole tires in cement kilns would have no more deleterious effect on emissions than burning coal alone. Implicit in this conclusion is that normal operation of cement kilns on coal does not have any adverse effect on ambient air quality. Based on measured stack emissions and the dispersion modelling of Conestoga Rovers & Associates, the estimated ground level pollutant concentrations for the Brookfield plant firing coal and coal with supplemental fuel were all below accepted health standards. However, because of the considerable variability in the measured emission data for plants using TDF as a supplemental fuel it is simply not possible to make predictions with any degree of certainty about changes in the emissions at the Brookfield site as a result of co-firing with whole tires.

7.0 Recommendations

Based on the uncertainty in the measured emission from cement kilns utilizing TDF as supplemental fuel, the site-specific conditions at the Brookfield plant, and the concerns raised by local citizens, the following recommendations are made.

1. Extensive baseline testing of emissions at the Brookfield plant running under the normal range of operating conditions should be undertaken. Such testing should include the range of fuel combinations (coal, used shingles, and waste oil) typically fired. Since it is highly probable that kiln operation and the feedstock itself contribute significantly to emission levels, the programme of baseline testing should be designed to properly measure emissions under a range of normal operating conditions and during upset conditions.

2. Off-site measurements of ground level concentrations of emissions should be undertaken during the baseline stack emissions testing programme. Detailed air dispersion modelling should be used, in conjunction with the measured stack emission data and measured ground level concentrations, to determine a baseline of the surrounding ground level pollutant concentrations.

3. A comprehensive pilot testing programme to measure emissions during co-combustion with whole tires should be undertaken. The test programme should be developed within a risk management framework so that informed decisions about managing the risks associated with TDF usage can be made. Implicit in this approach is that any concerns raised from the baseline testing programme would be addressed before proceeding to the pilot test with TDF. Likewise, if during the pilot testing emissions exceeded established criteria levels, then the testing would stop until additional control measures were put in place. Air dispersion modelling would be used to quantify any changes in off-site ground level pollutant concentrations.

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APPENDIX A: Dioxin and Furan Emission Limits

Normally the only dioxin and furan molecules that are the focus of regulatory action are those with chlorine atoms in the 2, 3, 7 and 8 positions. There are 17 of these compounds as listed in Table A1. Different dioxin and furan compounds vary by several orders of magnitude in their ability to cause adverse health effects in laboratory animals. The most toxic of the chlorinated dioxin and furan molecules in laboratory animals is 2,3,7,8-tetachlorodibenzo-p-dioxin (TCDD known as Agent Orange).

Dioxins and furans are usually encountered as mixtures, therefore a system has been developed to estimate the toxicity of a mixture relative to the most toxic dioxin compound (2,3,7,8-TCDD). The potency of the other 16 compounds relative to 2,3,7,8-TCDD, is referred to as the toxic equivalency factor, or TEF (see Table A1). Toxic Equivalent Factors were developed by the World Health Organization in 1998. The WHO assigned potency values to 17 dioxin and furan compounds, relative to the most potent assigned a value of 1. The other 193 chlorinated dioxin and furan compounds do not have chlorine atoms in the 2, 3, 7 and 8 positions and are not considered as posing significant health and environmental risks. Efforts to revise the TEF values over the years (see EPA-NCEA (2004) have resulted in there being two systems for quantifying toxic equivalents: **(1)** the WHO TEF values reported in a scientific paper by van den Berg *et al.* (1998); and **(2)** the International or I-TEQs which were established in 1989 on the recommendation of the NATO Committee on Challenges to Modern Society (NATO/CCMS). These TEFs were adopted by Canada in 1990 and are given in Table A1. Although the WHO-TEF values are slightly different from the I-TEF values which can change the TEQ reported for a particular mixture, little difference usually exists between toxicity potential between the I-TEFs and WHO-TEFs when it comes to characterizing risk.

Table A1: Toxic Equivalent factors (TEFs) [after MOE, 2004]

Congener	**NATO/CCMS (1989)**	**Congener**	**NATO/CCMS (1989)**
PCDDs		PCDFs	
2,3,7,8-TCDD	1	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	0.5	1,2,3,7,8-PeCDF	0.05
1,2,3,4,7,8-HxCDD	0.1	2,3,4,7,8-PeCDF	0.5
1,2,3,7,8,9-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDD	0.1	1,2,3,7,8,9-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8,9-OCDD	0.001	2,3,4,6,7,8-HxCDF	0.1
		1,2,3,4,6,7,8-HpCDF	0.01
		1,2,3,4,7,8,9-HpCDF	0.01
		1,2,3,4,6,7,8,9-OCDF	0.001