KOOGLER & ASSOCIATES, INC.
ENVIRONMENTAL SERVICES
4014 NW 13th STREET
GAINESVILLE, FL 32609-1923
352/377-5822 ▪ FAX/377-7158

KA 624-09-12
July 26, 2010

Ms. Christy Devore
Bureau of Air Regulation
Florida Dept. of Environmental Regulation
2600 Blair Stone Road, MS 5500
Tallahassee, Florida 32399-2400



*RE: Project No. 1210465-020-AC*
*__Additional__ Response to RAI Letter dated May 21, 2010*
*Alternative Fuels Materials Testing, SAC Cement Kiln 1*
*Branford, Suwannee County*

Dear Ms. Devore:

As follow up to my initial RAI response letter dated July 24, 2010, I am submitting to you the enclosed additional information which further addresses the requested Item 7 of the RAI. Enclosed are three attachments provided by Pennsylvania DEP from their file to authorize the carpet-derived fuel trial burn at the Lehigh cement plant. In accordance with Rule 62-4.050(3), I have sealed this letter with enclosure as certification by a professional engineer. Please feel free to contact me at (352) 377-5822 or mlee@kooglerassociates.com or Krishna Cole, Suwannee American Cement at (386) 935-5023 or krishnac@suwanneecement.com, if you have any questions regarding this submittal. I sincerely appreciate your time and consideration for this innovative project.

Regards,

Max Lee, Ph.D., P.E.

7/26/10
Date

cc: Krishna Cole, SAC

Cc: via email
Tom Messer, SAC: tomm@suwanneecement.com
Joe Horton, SAC: jbhorton@vcnainc.com
Celso Martini, SAC: cmartini@suwanneecement.com
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Heather Abrams, EPA Region 4: abrams.heather@epa.gov
Victoria Gibson, FDEP: Victoria.gibson@dep.state.fl.us

ATTACHMENT 1. PaDEP – Request for Determination and Supporting Information

LEHIGH
HEIDELBERGCEMENT Group

**Lehigh Cement Company**
537 Evansville Road
PO Box 619
Blandon, PA 19510
Phone (610) 926-1024
Fax (610) 926-1906

April 26, 2004

Mr. Roger Fitterling
Pennsylvania Department of Environmental Protection
Air Quality Program
Reading District Office
1005 Cross Roads Boulevard
Reading, PA 19605

RE: RFD for Trial Use of Carpet as Alternative Fuel
Lehigh Cement Company - Evansville Plant

Dear Mr. Fitterling:

Please find enclosed the RFD for the proposed carpet trial at Lehigh Cement-Evansville. This trial will be conducted at the request of Georgia Tech University and the American Society of Mechanical Engineers (ASME).

Please contact me if there is any additional information you require regarding this matter.

Sincerely,

Charles Bortz

Charles Bortz
Environmental Coordinator
610-926-1024 x291
cbortz@lehighcement.com

2700-PM-AQ0017 7/2001

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF AIR QUALITY

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# Request for Determination of Requirement for Plan Approval/Operating Permit (RFD)

**(Submit in Triplicate)**

**A.** Application is being made for: *[please mark the appropriate case(s)]*

☒ Exemption from Plan Approval ☐ Exemption from Operating Permit

**Physical Changes of Minor Significance**

☒ Changes Do Not Add New Equipment (See 25 Pa. Code § 127.14(c)(1)). Physical changes of minor significance must not violate the terms of an operating permit, the Pennsylvania Air Pollution Control Act (APCA), the Clean Air Act or regulations adopted thereunder. In addition, these changes can not result in emission increases above the emissions allowable in the operating permit or result in an increased ambient air quality impact for an air contaminant. Changes may be made within seven (7) days after the Department's receipt of a written request unless the Department requests additional information or objects to the changes.

☐ Changes Add New Equipment (See 25 Pa. Code § 127.14(c)(2)). Physical changes of minor significance must not violate the terms of an operating permit, the APCA, the Clean Air Act or regulations thereunder. In addition, these changes, which add new equipment, can not result in emission increases above the emissions allowable in the operating permit or result in an increased ambient air quality impact for an air contaminant. Changes can be made within 15 days after the Department's receipt of a written unless the Department requests additional information or objects to the changes.

**B.** Narrative Source Description (Include: process description, control device, exhaust volume, stack data, schematic flow diagram, material data safety sheet and any other pertinent information - attach additional sheets as needed):

See attached pages referencing carpet alternative fuel.

**C.** Facility Name: Lehigh Cement Company — Plant Name: Evansville Plant

**D.** Mailing Address: 537 Evansville Road, Fleetwood, PA 19522

**E.** Contact Person: Charles Bortz — Title: Environmental Coordinator

**F.** Telephone Number: 610-926-1024 — **G.** Federal ID #: 23-0797050

**H.** Current Operating Permit No., if any: Title V Permit No: 06-05002 — **I.** Date of Installation: NA

**J.** Location of Source(s): 537 Evansville Road, Fleetwood, PA 19522

**K.** Municipality/Township: Maiden Creek — County: Berks

I, Robert Breyer, certify under penalty of law as provided in 18 Pa. C. S.A. § 4904 and 35 P.S. § 4009(b)(2), that based on information and belief formed after reasonable inquiry, the statements and information contained in this form are true, accurate and complete.

(Signed) [signature] Date: 4-26-04

Name (typed) Robert Breyer Title: Plant Manager

L. Estimated Emissions *(Attach calculations and basis for estimated emissions)*:

| Pollutant(s) | Emissions (lbs/hr) | Emissions (tons/year) |
|---|---|---|
| No new or increase in emissions expected. | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

M. List all source(s) exempted from permitting within last five years. This listing should include sources that were exempted under a Request for Determination for Plan Approval/Operating Permit (RFD).

| Source | Date Installed | Department Determination, if any |
|---|---|---|
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |

N. Will the construction or modification of the source covered under this RFD increase emissions from other sources at the facility? ☐ Yes ☒ No

If yes, describe and quantify emission increases on separate sheet(s).

Will the construction or modification of the source be subject to 25 Pa. Code, Subchapter E, New Source Review (NSR) requirements or Prevention of Significant Deterioration (PSD) of Air Quality regulations?

☐ Yes ☒ No

**OFFICIAL USE ONLY**

Date Received: April 28, 2004 Reviewed By: Roger Fitterling

☒ A plan approval is not required for this source. (See 25 Pa. Code § 127.14(a)(1)-(9)).

☐ An operating permit is not required for this source. (See 25 Pa. Code § 127.443 (a)).

☐ The source(s) do(es) not qualify for exemption. Applicant is required to submit a plan approval and/or operating permit application.

[signature] Roger A Fitterling APCE III

Signature Name and Title

July 7, 2004

Date

***Remarks:*** See attached letter.

## Abstract

Five billion pounds of waste carpet are disposed of in the U.S. each year, with nearly this entire stream currently going to landfills. Much of this waste contains nylon, a high value polymer that can potentially be recycled. Economic studies performed by Georgia Institute of Technology (Georgia Tech) have indicated that the recycling of valuable materials in carpet could be promoted if at the same time there were outlets for the low-value materials, such as the polymers used in the backing and the calcium carbonate filler. These studies have shown that cement kilns may be an excellent outlet for the materials that cannot be economically recovered. Cement kilns can use the non-recycled portion of the waste carpet stream as both fuel (~10,000 BTU/lb heating value) and raw feed materials (calcium carbonate, which makes up 40% of the carpet by weight). The cement industry is a leader in use of other alternative fuels and materials, but little has been done with waste carpet in the U.S. partly due to materials handling issues and concerns. At the request of Georgia Tech, the American Society of Mechanical Engineers (ASME) Research Committee on Industrial and Municipal Waste (RCIMW) is initiating a combined research and demonstration program to address the technical issues involved with burning waste carpet in cement kilns. These issues include materials handling (transportation, size reduction, conveying, and feeding approaches); potential impact on product quality; impact on process operations; and impact on environmental emissions. The Program will also involve economic studies to incorporate new information into models developed previously by Georgia Tech. Expected outcomes include technical reports and workshops for technology transfer.


## Plant Process Description

The cement rotary kilns are refractory lined throughout their length and employ kiln chain to aid in the transfer of heat to the feed materials. Kiln feed is a proportioned mixture of calcium, iron, silica, and alumina materials ground to a suitable fineness. Limestone (calcium carbonate) is the primary kiln feed component.

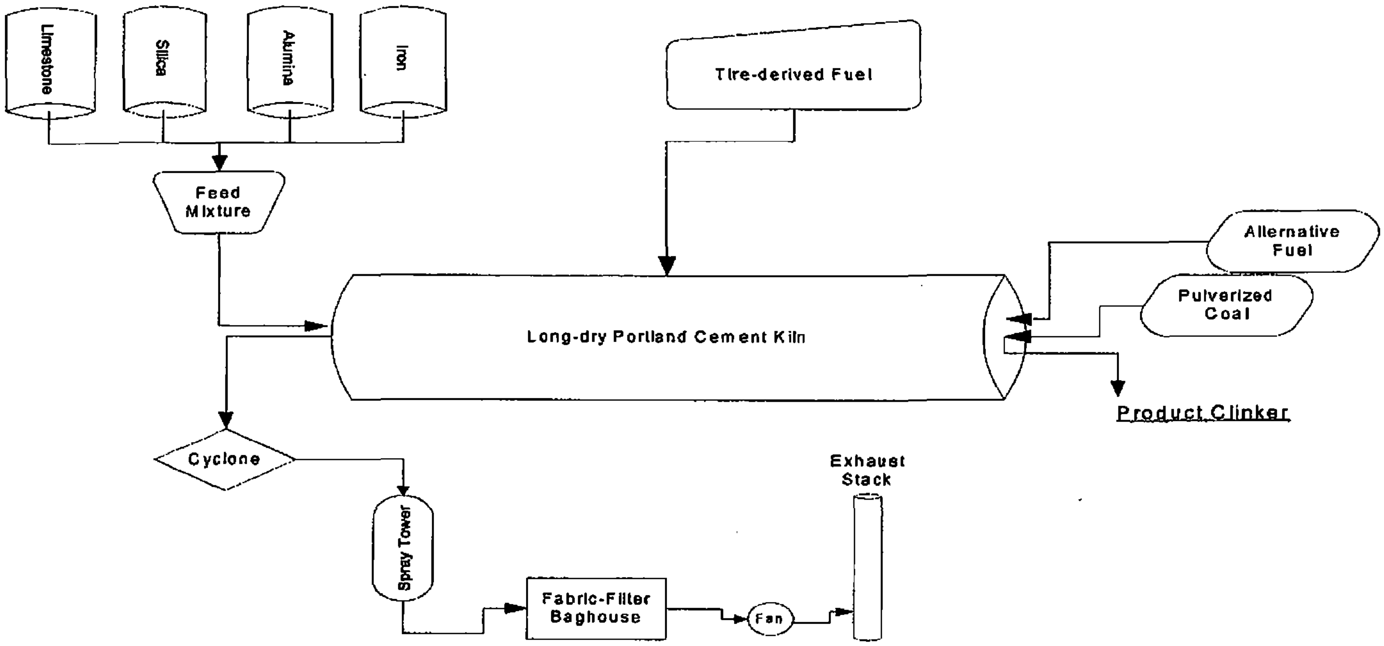
Each kiln line consists of the kiln and cooler and each with a new cyclone, new high-pressure water atomized gas conditioning tower, new fabric-filter baghouse, new stack and associated ductwork. Each kiln system also has a dedicated subsystem to handle material collected at the conditioning towers and fabric-filter baghouses.

The fabric-filter baghouses are designed for an exhaust volume of 321,000 acfm and an inlet temperature of 500 °F. The typical operating exhaust volumes, based on previous stack testing results, is approximately 145,000 acfm and a stack temperature of about 400 °F.

Each fabric-filter baghouse has its own stack; both of these stacks are identical in configuration. They are double walled stacks, with a 10 feet I.D. and 11 feet O.D. and 213.3 feet (65 meters) in height. See process schematic below.

Evansville Plant

Portland Cement Manufacturing
Process Schematic




## Trial Test Purpose

Lehigh Cement Company has agreed to be a host cement plant for this trial. The intent of this trial is to determine process performance and product quality utilizing carpet as an alternate fuel. Lehigh plans to introduce these materials to our "number one" kiln. We will use the materials at increasing levels of replacement and study process performance simultaneously. Product sampling and analysis will be conducted to ensure clinker is within quality control parameters.

## Material Transportation and Staging

W.D. Zwicky & Son Inc., specializing in materials processing, will provide size reduction and transportation for the carpet material. Material will be delivered in covered 100 cubic yard capacity trailers. Delivery will be made from the Zwicky property located next to the Evansville plant property.

## Fuel Sizing

Lehigh estimates two inch minus as material particle size. This is subject to change based on process performance evaluation of different size material.

## Fuel Delivery System

Lehigh will utilize equipment that will allow material to be off loaded from a walking floor trailer onto a conveyor and transported to a hopper. From the hopper the material enters a weigh feeder to an air lock rotary valve and into a six-inch blower transport line for delivery to the kiln firing zone. Airflow rate from the blower for fuel transport is approximately 1,400 acfm at 215°F. Airflow rates from the coal mill range from 36,000 to 48,000 acfm at 170°F. The secondary fuel delivery point within the kiln is approximately ten inches directly above the point of entry for the coal. All of the alternate fuel transport air will be exhausted into the kiln.

**Emissions and Gas Residence Time**

Below is a summary of the gas flows as derived from the kiln model for Evansville and a detail of the retention time calculation. The notes below give explanation for the calculations.

Notes:

1. All calculations in the kiln gas model are derived and checked against field measurements. Gas flow at the kiln inlet is calculated from combustion gases, water in kiln feed and $CO_2$ from kiln feed.
2. Kiln feed loss is 34% by weight when ignited. Total loss is assumed as $CO_2$.
3. For calculation of retention time an average calcination rate of 50% is assumed for the distance from the kiln outlet to the chain section. This is done to account for the liberation of $CO_2$ from the kiln feed as material travels through this zone. Doing this averages the amount of $CO_2$ from the feed in the gas stream at any time in this kiln section. This should yield a representative average of the gas flow/velocity/retention time for this zone as a whole.
4. Average gas temperature from kiln outlet to chain section is assumed to be 1150°C or 2102°F.
5. Retention time shown is to the chain section only (before shell expansion).

Brian Forsythe
HTC-NAM
Process Engineer

| | | |
|---|---|---|
| Average Kiln Production During Testing | 1,250 mtpd | 1,375 stpd |
| Kiln Feed Rate | 88.5 mtph | 97.4 stph |
| Average Kiln Gas Data (to chains) | | |
| Normal Volume | 83,563 Nm3/h | |
| Actual Volume | 442,333 Am3/h | 260,196 acfm |
| Temperature | 1,150 C | 2,102 F |
| Pressure | -10 mmwg | -0.4 "H2O |
| Estimated gas retention time | 14.6 s | |
| Kiln Riser | | |
| Normal Volume | 91,226 Nm3/h | |
| Actual Volume | 305,187 Am3/h | 179,522 acfm |
| Temperature | 625 C | 1,157 F |
| Pressure | -25 mmwg | -1.0 "H2O |
| O2 level | 2.5 % | |
| Water To Spray Tower | 181.6 lpm | 48.0 gpm |
| Total Cooling Water | 181.6 lpm | 48.0 gpm |
| Spray Tower Exit | | |
| Normal Volume | 113,830 Nm3/h | |
| Actual Volume | 190,919 Am3/h | 112,305 acfm |
| Temperature | 175 C | 347 F |
| Pressure | -75 mmwg | -3.0 "H2O |
| False Air (kiln inlet to stack) | 29,078 Nm3/h | |
| Stack Gases | | |
| Normal Volume | 142,907 Nm3/h | |
| Actual Volume | 225,199 Am3/h | 132,470 acfm |
| Temperature | 150 C | 302 F |
| Pressure | -25 mmwg | -1.0 "H2O |
| O2 level | 5.50% | |
| June 5, 2002 Average Stack Test | 241,407 Am3/h | 142,004 acfm |
| Relative error of calculation | 6.71 % | |

## Evansville Kiln Model

| | | |
|---|---|---|
| Total gases to chains | 115,623 kg gas/h | |
| Normal volume to chains | 83,563 Nm$^3$ gas/h | |
| Temperature to chains | 1,150 C | 2102 F |
| Static pressure to chains | -10 mmwg | -0.39 "$H_2O$ |
| Actual density of gases to chains | 0.261 kg/am$^3$ | |
| Actual flow rate to chains | 442,333 am$^3$/h | 260,196 ACFM |
| Kiln diameter (ID to Chain Section Inlet) | 4.120 m | 13.5 ft. |
| Kiln Cross Section (Discharge to Chain Section Inlet) | 13.33 m$^2$ | |
| Average kiln gas velocity (to chain section) | 9.22 m/s | |
| Kiln Length (Discharge to Chain Section Inlet) | 135 m | 442.9 ft. |
| **Gas retention time (to Chain Section Inlet)** | **14.6 s** | |

## Fuel Characteristics

### Chemical Properties of Carpet

**Proximate analysis ( wt. %, dry basis)**

| | |
|---|---|
| **Ash** | 16,2 |
| **Water** | |
| **Volatiles** | - |
| **HHV (kJ/kg)** | 21,874 |
| **LHV (kJ/kg)** | 20,612 |
| **HHV (Btu/lb)** | 9,424 |
| **Ultimate analysis (wt. %, dry basis)** | |
| **C** | 45,1 |
| **H** | 5,78 |
| **O** | 30,1 |
| **N** | 2,77 |
| **S** | 0,12 |
| **Cl** | 0,405 |
| **F** | - |
| **Br** | - |
| **Total:** | 100,4 |

### Physical Properties

| | |
|---|---|
| **State** | Solid |
| **Vapor Pressure** | N/A |
| **Bulk Den, lb/cu3** | N/D |

**N/A - Not applicable**
**N/D - Not determined**

**Reference**

1 S.A.H.Moorman et al: Emissies uit bijstoken, verbranden en vergassen van niet-gevaarlijke afvalstromei tot BLA en AVI. Hoofdrapport, Delft (Netherlands), Centrum voor Energiebesparing en schone technolo; 00.5713.01, 69 p. (2000).

### Fuel Sampling

Lehigh will work in conjunction with the other participants to develop an appropriate incoming carpet fuels sampling plan. See attached paper written on a recent study that was conducted.

**Emission Sampling**
Monitoring using existing CEMS would be done during the duration of the trial. Refer to the attached paper "Emissions Study of Co-firing waste Carpet in a Rotary Kiln".

**Fuel Replacement Rate, Duration and Volumes**
Duration of the trial is dependent on feed rates and run times. To allow for flexibility in the trial and scheduling, Lehigh requests a trial period to conduct these tests which would allow for 1000 tons of carpet to be burned. The time period will need to be variable due to work being done on the sizing of the material. We would propose to run a preliminary 20 ton run in May 2004 to early June 2004 to evaluate the suitability of the existing alternative fuel dosing system in conveying the carpet material. After a successful carpet dosing trial we would propose to begin the trial on or about July 1, 2004. The trial would then progress for the approximately 60 operational days that would be required to burn the remainder of the aforementioned 1000 tons of material.

**Preliminary Operational Plan**
The following schedules will vary somewhat due to unplanned events with material handling and equipment troubleshooting.

Plan will include:

1. Preliminary short 20 ton run to determine the suitability of the existing dosing system to handle the waste carpet- May 2004 to June 2004.
2. Begin actual longer term trial approximately July 1, 2004. Start by feeding short runs of material, one hour or less to develop calculations of feed rates based on product densities, screw speeds, etc.
3. Adjust airflow rates, screw rates, and other system adjustments to provide optimal material delivery to kiln.
4. Any other general debugging required prior to starting the planned feed rate trials with the feed system.
5. Perform full feed rate trials. Accumulate feed and emissions data.
6. Perform normal quality control tests of raw feed, fuel, and clinker during the test burn

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# Emissions study of co-firing waste carpet in a rotary kiln

Paul Lemieux[a,*], Eric Stewart[a], Matthew Realff[b], James A. Mulholland[b]

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[b]Georgia Institute of Technology, Atlanta, GA 30332, USA

Received 12 May 2003; revised 20 October 2003; accepted 28 October 2003

**Abstract**

Post-consumer carpet represents a high volume, high energy content waste stream. As a fuel for co-firing in cement kilns, waste carpet, like waste tires, has potential advantages. Technological challenges to be addressed include assessing potential emissions, in particular NO emissions (from nylon fiber carpets), and optimizing the carpet feed system. This paper addresses the former.

Results of pilot-scale rotary kiln experiments demonstrate the potential for using post-consumer waste carpet as a fuel in cement kilns. Continuous feeding of shredded carpet fiber and ground carpet backing, at rates of up to 30% of total energy input, resulted in combustion without transient puffs and with almost no increase in CO and other products of incomplete combustion as compared to kiln firing natural gas only. NO emissions increased with carpet waste co-firing due to the nitrogen content of nylon fiber. In these experiments with shredded fiber and finely ground backing, carpet nitrogen conversion to NO ranged from 3 to 8%. Conversion increased with enhanced mixing of the carpet material and air during combustion. Carpet preparation and feeding method are controlling factors in fuel N conversion.


*Keywords:* Waste carpet; Rotary kiln; NO emissions

## 1. Introduction

### 1.1. Scope of problem

Cement kilns represent a very energy intensive sector, requiring energy inputs ranging from 3200 to 5000 kJ/kg of clinker produced (Akgun, 2003). The cement industry has placed a high priority on energy savings as a primary means of achieving cost reductions. The auxiliary fuel requirements of cement kilns represent the main energy cost associated with cement production. The auxiliary fuel most commonly used is coal. Some cement plants have successfully replaced a portion of their coal feed with other high heating value waste-derived fuels including tires and tire-derived fuel (Reisman, 1997) or hazardous waste (US EPA, 2003). Waste carpet is another potential auxiliary fuel that could be used in cement kilns.

Carpet is an important component of homes throughout the world, providing warmth and comfort as well as aesthetic function. In the US, approximately 5–6 billion lbs of carpet is sold annually, of which 60% is for replacement (Statistical Report, 2001). This leads to a large waste stream that is bulky and widely dispersed at its point of origin. Carpet does not compress well, and its bulk makes it difficult for landfills to handle. Perhaps more importantly, this waste stream is a significant quantity of material and, if it could be recovered, would represent a significant economic opportunity. In spite of considerable effort in the past decade to develop recycling technologies for carpet wastes, most carpet continues to be disposed of in landfills (US EPA, 2002). The development of economically viable, environmentally sound, high volume, robust systems for dealing with carpet waste would move the carpet industry closer to its goals of environmental stewardship and protection.

The goal of reducing the flow of carpet to landfills has been explicitly recognized by the industry in its commitment to several states and the EPA in a 'Memorandum of Understanding' (CRI, 2002). This memorandum has the explicitly stated goal of diverting 2 billion lbs of post-consumer carpet from landfills. Fig. 1 shows a plot of the targets over the next decade. The disposal line represents estimates of how much carpet will be disposed of if no action to recycle or reuse it was taken-approximately 6.5 billion lbs. The total diversion is the target set by

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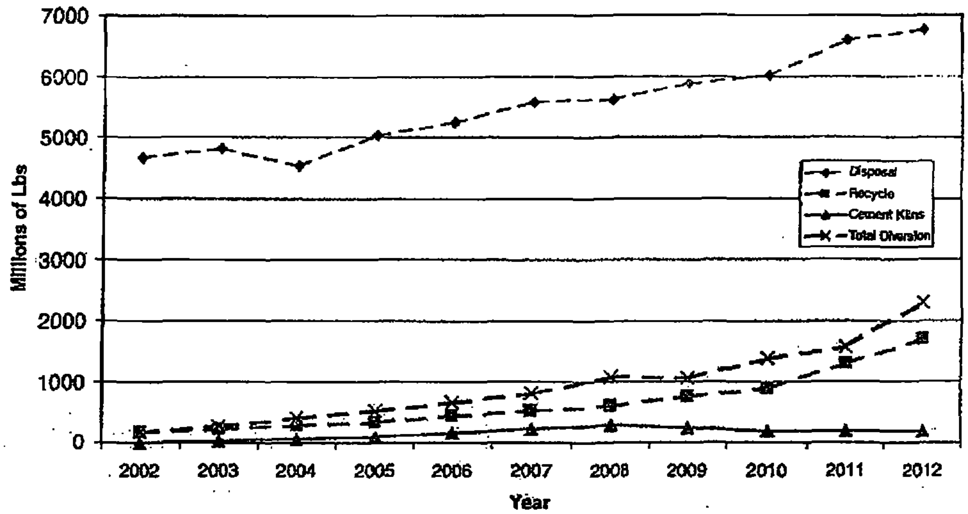


Fig. 1. US industry targets for carpet disposal.

the memorandum for carpet to be diverted from landfill to all other uses. The cement kiln line is the quantity that is targeted for use as an alternative fuel in cement kilns that has been negotiated in the memorandum. Fig. 1 also includes one potential high volume outlet for carpet, using it as a fuel in cement kilns. This option is an attractive one to help build the infrastructure for higher value outlets for portions of the post-consumer carpet. The target is to divert approximately 200 million lbs to cement kilns as an alternative fuel, as shown in Fig. 1. This target was established through the stakeholder negotiations, and it has been explicitly accepted that it may be increased provided evidence that its use as an alternative fuel is environmentally and economically sound and could stimulate recycling infrastructure growth.

### 1.2. System needs

The recycling of carpet faces a 'chicken and egg' dilemma. The collection infrastructure is hard to develop without markets for particular products, and potential markets are difficult to develop without specific estimates of collection costs and the ability to rapidly ramp up the provision of material. In addition, many recycling activities are extremely sensitive to prices of competing commodities and may be forced to shut down, leaving the collection infrastructure in the lurch. The fragility of the system, particularly if the outlets represent a significant fraction of the overall recycling activity for the product, leads to a high risk premium on capital investment in collection and, hence, an overall higher cost of the feedstock. Thus, carpet recycling would be greatly enhanced if there were large volume outlets that were less sensitive to the swings in commodity prices. These outlets would be useful in two ways. First, they would provide a steady demand for material that could be used to develop the collection infrastructure. Second, they would provide a buffer for the collection system if other, more risky, recycled products were to fail. This suggests a pattern of system development that has been followed by tire recycling in which using tires as fuel has been followed by the development of other higher-value outlets.

The use of carpet in cement kilns fulfills this systemic need for a high volume outlet and is particularly suitable in three ways. First, carpet contains a significant fraction of calcium carbonate as filler in the backing. This calcium carbonate would form a significant ash fraction in regular power boiler applications, but is a component of the cement kiln feed and, hence, is incorporated into a useful product. Second, cement kilns are widely distributed throughout the US, and, given the cost of shipping the bulky carpet material, finding outlets relatively close to the points of generation would have significant advantages in cost. Third, with the exception of PVC backed carpet tile products, cement kilns can accept all the types of carpets as a fuel.

As mentioned before, however, it is important to establish that the use of carpet as a fuel in cement kilns is both environmentally and economically sound. In this paper, one aspect of using carpet as a fuel is explored—its emissions. In particular, there is the potential for increased emission of oxides of nitrogen when carpet is used as a fuel because nylon face fiber has high nitrogen content. In addition, there is the potential for trace contaminants to be present in post-consumer carpet waste. On the other hand, carpet is likely to be a cleaner burning fuel than coal with respect to some emissions, such as mercury.

To assess the feasibility of using post-consumer carpet waste as fuel in cement kilns, more information is needed on potential emissions from the combustion of carpet. The objectives of this study are to use a pilot-scale rotary kiln test facility to address the impact of carpet waste co-firing on emissions of incomplete combustion products, oxides of nitrogen, and mercury. Rapid volatilization of the waste carpet could lead to transient puffs containing incomplete combustion products. The high nitrogen content of nylon fiber could lead to higher NO emissions. Any mercury contamination in waste carpet, while not expected, could lead to emission of this volatile metal.

## 2. Experimental

### *2.1. Rotary Kiln*

Experiments were performed in EPA's Rotary Kiln Incinerator Simulator (RKIS), a 73 kW (250,000 Btu/h) natural gas-fired rotary kiln equipped with a 73 kW (250,000 Btu/h) secondary combustion chamber (SCC), shown in Fig. 2 (Lemieux et al., 2002). After exiting the SCC, the flue gases pass through a long horizontal duct, where organic species are sampled. Gases then pass through a flue gas cleaning system (FGCS) consisting of an afterburner, spray quench, baghouse, and wet scrubber, before being released to the atmosphere. The main burner was fired at two thermal input rates during the experiments so that a low and high temperature condition could be achieved. For all of these experiments, the SCC was not fired.

The RKIS is equipped with continuous emission monitors (CEMs) for oxygen ($O_2$), carbon dioxide ($CO_2$), carbon monoxide (CO), nitric oxide (NO), and total hydrocarbons (THCs), at the exits of both the rotary kiln section and the SCC. In addition to the conventional CEMs, a PS Analytical (PSA Sir Galahad) CEM for mercury (Hg) and an Ecochem (Model PAS 2000) polycyclic aromatic hydrocarbon (PAH) CEM were used. Measurements of volatile organic compounds (VOCs) were made using Tedlar bags and gas chromatography/mass spectrometry (GC/MS) (US EPA, 1994) as well as with an online GC (Ryan et al., 1998). Temperatures are measured using a series of Type-K thermocouples (TCs). Sulfur dioxide ($SO_2$) was not measured. Carpet sulfur content (0.1–0.2%, Table 1) is significantly lower than the sulfur content of a typical coal used as primary fuel. Therefore, the co-firing of waste carpet in a cement kiln is not expected to increase $SO_2$ emissions.

### *2.2. Carpet waste*

Carpet material was supplied by Dupont in the form of a shredded fiber fraction (carpet fiber) and a dust-like fraction representing highly ground backing material (carpet fines). The carpet fiber was primarily nylon 6,6. Major constituents of the backing are filler consisting mostly of calcium carbonate and latex/rubber. The carpet fines fraction contains both ground backing as well as some ground fiber. The ratio of face to backing in broadloom carpet products, is approximately 1:1 face weight to backing weight, but the composition we feed to the kiln reflected the outcome of the separation process used by Dupont in their recycling system.

A proximate and ultimate analysis of the fiber and fines were performed, and the results are shown in Table 1. The carpet fiber results of 59.1% carbon, 9.3% hydrogen, 8.5% nitrogen, and 14.5% oxygen are consistent with a high

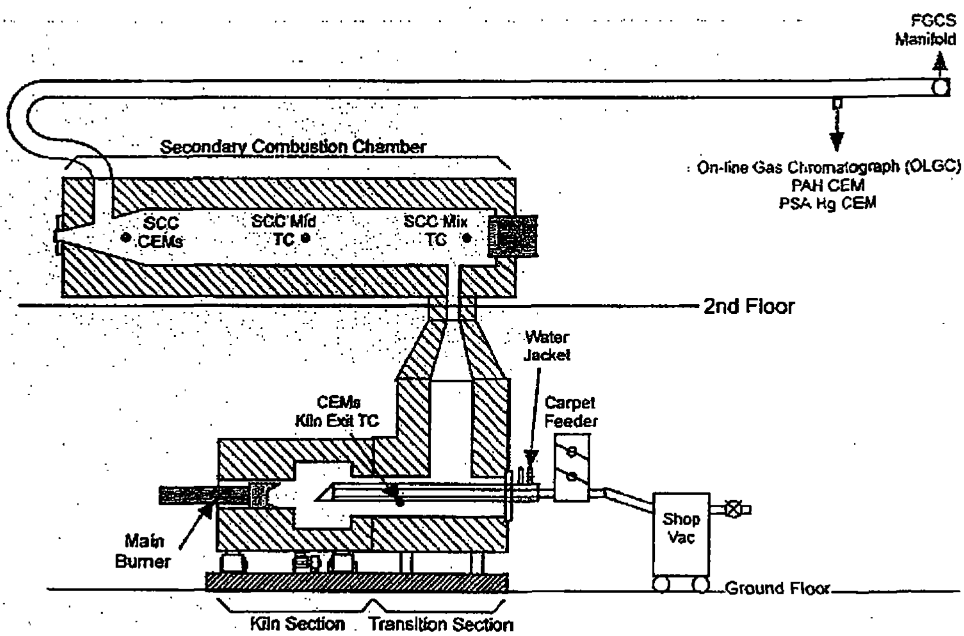


Fig. 2. Rotary kiln incinerator simulator.

Table 1
Results from proximate and ultimate analysis of carpet material

| | Carpet fiber | Carpet fines |
|---|---|---|
| *Ultimate analysis* | | |
| Moisture (%) | 0.8 | 1.5 |
| Carbon (%) | 59.1 | 38.3 |
| Hydrogen (%) | 9.3 | 4.4 |
| Nitrogen (%) | 8.5 | 4.0 |
| Sulfur (%) | 0.10 | 0.24 |
| Chlorine (%) | 0.058 | 0.11 |
| Ash (%) | 7.7 | 29.2 |
| Oxygen (by difference) (%) | 14.5 | 22.3 |
| Heat of combustion (kJ/kg) | 29,309 | 12,973 |
| *Proximate analysis* | | |
| Moisture (%) | 0.8 | 1.5 |
| Volatile matter (%) | 91.6 | 69.2 |
| Ash (%) | 7.7 | 29.2 |
| Fixed carbon (by difference) (%) | 0.00 | 0.05 |

Table 2
Results from XRF analysis of carpet material (mass%)

| | Carpet fiber (%) | Carpet fines (%) |
|---|---|---|
| Al | 0.0473 | 0.250 |
| Br | 0.0122 | 0.0025 |
| Ca | 1.01 | 9.84 |
| Cl | 0.0443 | 0.184 |
| Co | 0.0017 | ND |
| Cr | ND | 0.0006 |
| Cs | 0.0013 | ND |
| Cu | 0.0027 | ND |
| F | 0.0240 | ND |
| Fe | 0.0184 | 0.0713 |
| I | 0.0018 | ND |
| K | 0.0233 | 0.0572 |
| Mg | 0.0169 | 0.322 |
| Mn | 0.0006 | 0.0040 |
| Na | 0.0717 | 0.280 |
| P | 0.0152 | 0.0366 |
| S | 0.107 | 0.199 |
| Sb | ND | 0.0051 |
| Si | 0.0266 | 0.266 |
| Sr | ND | 0.0083 |
| Ti | 0.126 | 0.116 |
| Zn | 0.0018 | 0.0083 |

ND, not detected.

nylon content; pure nylon 6,6 polymer contains 63.7% carbon, 9.7% hydrogen, 12.4% nitrogen, and 14.2% oxygen. The presence of nitrogen in the carpet fines indicates the degree to which the fines contain carpet fiber in addition to carpet backing. The high ash content of the carpet fines is due to the backing filler. Sulfur may result from rubber in the carpet backing. Chlorine is likely a contaminant (e.g. salt), resulting from either carpet manufacture or carpet use.

To obtain more information on the ash content, triplicate samples of the carpet fines and fibers were also subjected to elemental analysis by X-Ray Fluorescence (XRF). The results from XRF analysis are shown in Table 2. As expected, the predominant element found in the samples was calcium, the major element in the filler. The source of minor constituents in the fines (in order of most abundant to least, magnesium, sodium, silicon, and aluminum) may be contaminants in the filler or contaminants resulting from carpet use. Other trace metals may be used as catalysts in carpet manufacture or may be contaminants. The presence of fluorine and bromine in the carpet fiber is likely due to flame retardant application. The presence of many of the same elements in both fiber and fines samples indicates the incomplete separation of fiber and backing.

### *2.3. Carpet waste feeding system*

Due to the low bulk density of the material, an air entrainment method was used for feeding carpet. The material was introduced directly into the rotating drum section of the rotary kiln (rotating at 0.5 rpm) using the feeder system shown in Fig. 2. For most of the runs, the fiber and fines were combined in a mass ratio of two parts fiber to one part fines and fed in a semi-continuous manner. Based on a desired hourly feed rate, measured amounts of carpet material sufficient for 1 min of feeding were weighed; then aliquots from that quantity were manually introduced into the feeder at 5–10 s intervals. Three nominal feed rates were used, representing 2.3, 1.1, and 0.57 kg/h (5.0, 2.5, and 1.25 lb/h, respectively).

Air was used to deliver carpet fiber and fines to the combustor. The molar ratio between the air being introduced through the burner and the feeder was used as a variable of interest and was varied by manipulating the mass flow controller on the main combustion air and the manual valve on the inlet of the shop vacuum used to supply air to the carpet feeder. The static pressure in the duct between the RKIS and the FGCS was adjusted to a constant value of 0.12 kPa (0.05 in. w.c.) so that air in-leakage around the seals was maintained at a constant value. Nominally, two feeder/burner air ratios were used in the tests, although the feeder/burner air ratios were estimated using material balance calculations that included an estimation of the air in-leakage to the rotary kiln around the seals.

### *2.4. Test matrix*

A series of tests were performed as shown in Table 3. Sixteen tests were performed, varying the kiln temperature, carpet feed rate, and feeder-to-burner air ratio. These experiments were conducted using the semi-continuous carpet feeding method described above with a mixture of two-thirds fiber and one-third fines. This composition reflected the outcome of the recycling process rather than the ratio of backing to face fiber in the carpet product. In addition to these tests, four additional experiments were conducted to evaluate emissions from the fiber and fines

Table 3
Experimental conditions and measurements

| | Kiln exit temperature (°C) | Feeder/burner air ratio | Carpet feed rate (percent of fuel) | Measurements |
|---|---|---|---|---|
| 2/3 fiber + 1/3 fines | 807 | 0.3 | 2.4 kg/h (29%) | $O_2$, $CO_2$, CO, NO, Hg, PAH |
| 2/3 fiber + 1/3 fines | 799 | 0.3 | 1.3 kg/h (15%) | $O_2$, $CO_2$, CO, NO, Hg, PAH |
| 2/3 fiber + 1/3 fines | 803 | 0.3 | 0.6 kg/h (7.3%) | $O_2$, $CO_2$, CO, NO, Hg, PAH |
| 2/3 fiber + 1/3 fines | 824 | 1.1 | 2.5 kg/h (29%) | $O_2$, $CO_2$, CO, NO, Hg, PAH |
| 2/3 fiber + 1/3 fines | 842 | 1.1 | 1.2 kg/h (15%) | $O_2$, $CO_2$, CO, NO, Hg, PAH |
| 2/3 fiber + 1/3 fines | 851 | 1.2 | 0.6 kg/h (7.6%) | $O_2$, $CO_2$, CO, NO, Hg, PAH |
| 2/3 fiber + 1/3 fines | 770 | 1.1 | 2.6 kg/h (30%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 776 | 1.1 | 1.3 kg/h (15%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 815 | 1.7 | 1.9 kg/h (20%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 771 | 3.2 | 1.2 kg/h (14%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 933 | 0.9 | 2.5 kg/h (19%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 946 | 1.2 | 1.3 kg/h (9.8%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 950 | 1.1 | 0.7 kg/h (5.1%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 954 | 1.7 | 2.5 kg/h (19%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 964 | 1.7 | 1.2 kg/h (9.2%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| 2/3 fiber + 1/3 fines | 966 | 1.7 | 0.7 kg/h (5.1%) | $O_2$, $CO_2$, CO, NO, THC, VOC |
| Fiber only | 970 | 1.7 | 1.8 kg/h (16%) | $O_2$, $CO_2$, CO, NO |
| Fiber only (one charge) | 970 | 1.7 | 28.6 g | $O_2$, $CO_2$, CO, NO |
| Fines only (one charge) | 970 | 1.7 | 13.0 g | $O_2$, $CO_2$, CO, NO |
| fines only (one charge) | 970 | 1.7 | 13.0 g | $O_2$, $CO_2$, CO, NO |

separately and to evaluate the effect of different methods of feeding carpet. Fiber was tested alone, fed both on a semi-continuous basis and as a single batch with a charge approximately 10 times the normal charge (that is, equivalent to the total of 10 charges fed using the semi-continuous method over a 1 min time interval). Duplicate experiments were performed with single charges of fines only (as opposed to multiple repeats of several fines—only charges).

## 3. Results and discussion

### 3.1. Overall results

With waste carpet providing up to 30% of the fuel heating value, semi-continuous feeding of the shredded fiber and ground fines resulted in steady combustion without transient puffs. Average concentrations measured at the kiln exit in the 16 semi-continuous experiments are shown in Table 4. Baseline conditions are defined as the RKIS operating conditions with no carpet feed. The only significant increase in emissions was that of NO, which increased by an average of 95 ppm. This translates to an average conversion of nitrogen in the carpet materials to NO of 5.3%. This will be discussed in more detail later.

Incomplete combustion products, including CO, THCs, VOCs, and PAHs, increased only slightly when waste carpet was co-fired with natural gas, and no statistically significant relationships were observed between these measurements and combustion conditions. Therefore, only average measurements across all experiments are presented in Table 4. CO concentration increased an average of 1.4 ppm, and PAH concentration increased by 2.5 $\mu g/m^3$. The only VOC increase observed was a small increase in benzene concentration. Total hydrocarbons were not detectable.

Mercury emissions were not detected above a background level of 1–2 $\mu g/m^3$. There is no evidence that the post-consumer carpet waste tested had any mercury contamination.

An XRF analysis of an ash sample taken from the kiln following testing indicates that 50–60% of the ash consists of calcium oxide, with the largest minor components being oxides of aluminum, silicon, magnesium, iron, and sulfur. This result is consistent with the XRF analysis of the carpet feed materials.

### 3.2. NO emissions

The dependence of NO emissions on carpet feeding rate, temperature, and feeder-to-burner air ratio can be seen

Table 4
Average kiln emission rates (expressed at dry, standard conditions, 7% oxygen in kiln)

| | Baseline | With carpet |
|---|---|---|
| NO | 85 ppm | 180 ppm |
| CO | 19.3 ppm | 20.7 ppm |
| THC | $<1$ ppm | $<1$ ppm |
| Benzene | 10 $\mu g/m^3$ | 14 $\mu g/m^3$ |
| PAH | 5 $\mu g/m^3$ | 7.5 $\mu g/m^3$ |
| Hg | 1–2 $\mu g/m^3$ | 1–2 $\mu g/m^3$ |

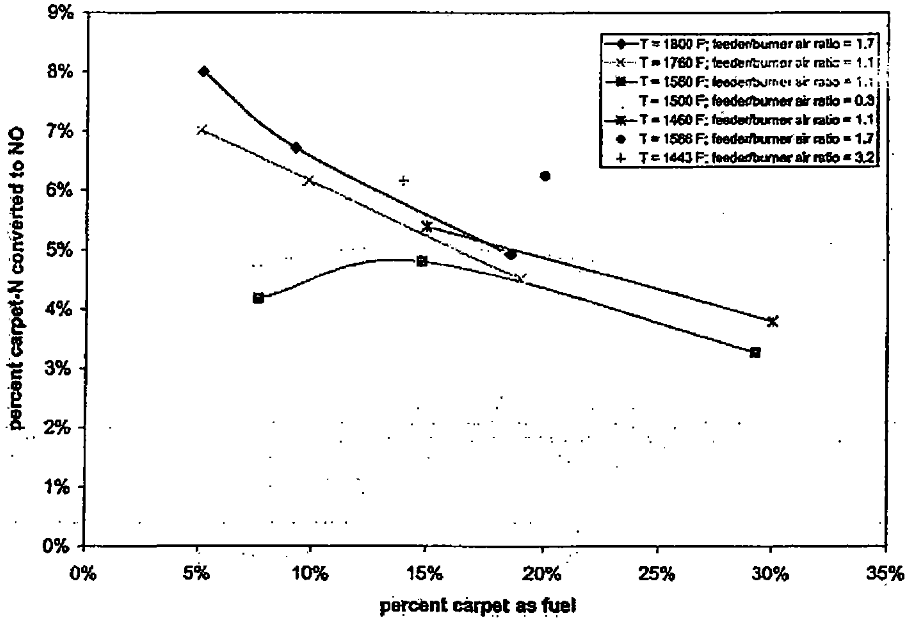


Fig. 3. Conversion of carpet nitrogen to NO in continuous feed tests.

in Fig. 3. Results from all 16 experiments with semi-continuous feed of two-thirds fiber and one-third fines are plotted. By taking the difference between NO concentration with carpet waste co-firing and NO concentration without co-firing (baseline) and normalizing to the amount of nitrogen input in the carpet, the percent carpet nitrogen converted to NO was estimated. Conversion was highest at low carpet feed rates, high temperature, and high feeder-to-burner air ratios. The low carpet feed rates and high feeder-to-burner air ratios result in greater mixing of carpet and air during combustion, resulting in higher fuel-NO emission rates. The temperature effect could be due to enhanced conversion of fuel-nitrogen to NO, or greater thermal NO formation. On average, the kiln exit temperature increased by 18 °C when carpet was co-fired.

These results suggest that the method of carpet preparation and feeding affects NO emissions. Excessive shredding and grinding of carpet so that it can be fed

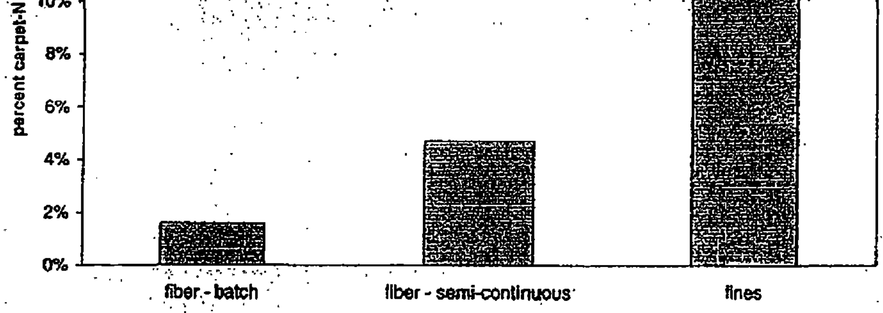


Fig. 4. Conversion of carpet nitrogen to NO in carpet fiber and fines.

Table 4
Aldehyde and Ketone Emissions Results, Average of 3 Tests

| | Baseline UF Coal | 10% Creosote Wood | 10% PCP Wood |
|---|---|---|---|
| | Emissions Factor (g/MJ) Basis | | |
| Acetaldehyde | < 8.12E-07 | ~ 1.51E-06 | < 7.42E-07 |
| Acetophenone | < 2.43E-06 | < 1.81E-06 | < 1.73E-06 |
| Formaldehyde | ~ 9.23E-07 | 9.41E-07 | ~ 1.06E-06 |
| Isophorone | < 3.66E-07 | < 3.19E-07 | < 3.54E-07 |
| Propionaldehyde | < 4.01E-07 | < 3.50E-07 | < 3.87E-07 |
| | Flue Gas Composition (dry ppb @3% $O_2$) | | |
| Acetaldehyde | < 1.4 | ~ 2.7 | < 1.3 |
| Acetophenone | < 1.5 | < 1.2 | < 1.1 |
| Formaldehyde | ~ 2.3 | 2.4 | ~ 2.6 |
| Isophorone | < 0.21 | < 0.18 | < 0.19 |
| Propionaldehyde | < 0.53 | < 0.46 | < 0.43 |

Notes: < indicates the value is below the detection limit
~ estimated value, indicates the measured value is below the quantitation limit or the measured value is above the calibration range

Table 5
Total Dioxin, Furan,and PAH Emissions Factor Results, Average of 3 Tests

| | Baseline UF Coal | 10% Creosote Wood | 10% PCP Wood |
|---|---|---|---|
| Total PCDD (g/MJ) | 1.73E-11 | 2.57E-12 | 5.51E-12 |
| Total PCDF (g/MJ) | 7.32E-12 | ND | 1.33E-12 |
| Total PCDD/PCDF (g/MJ) | 2.46E-11 | 2.57E-12 | 6.84E-12 |
| Total PAH (g/MJ) | 4.21E-08 | 2.44E-08 | ND |

continuously may result in greater fuel NO emission. To further investigate this hypothesis, experiments were performed with fiber and fines samples alone. Fiber samples were injected without fines both using the semi-continuous method used previously as well as using a single charge, 'batch' method in which a charge approximately a factor of 10 greater in size was injected. Fines were also fed separately. NO emission results are shown in Fig. 4.

The results clearly show the effect of enhanced mixing of carpet material and air during combustion. In the batch fed fiber experiment, 1.6% of the carpet nitrogen was converted to NO. In the semi-continuous fed fiber experiment, 4.7% of the carpet nitrogen was converted to NO. In the two fines-only duplicate experiments, 15.8 and 17.2% conversion of carpet nitrogen to NO was observed. In this latter experiment, mixing of the fuel nitrogen and air was great due to fine grinding of the carpet.

## 4. Conclusion

The pilot-scale rotary kiln experiments demonstrate the potential for use of post-consumer waste carpet as a fuel in cement kilns. The carpet has a high heating value, similar to that of a low-grade coal. The continuous feeding of shredded carpet fiber and ground carpet backing resulted in combustion without transient puffs and with almost no increase in CO and other products of incomplete combustion. Incomplete combustion products, including CO, THCs, VOCs, and PAHs, changed very little when waste carpet was co-fired with natural gas. For example, comparing average emissions with and without the carpet feed, CO concentration increased an average of 1.4 ppm and PAH concentration increased by 2.5 $\mu g/m^3$ with the addition of carpet. Emission of mercury, a potential contaminant in post-consumer carpet waste, was not observed. NO emissions increased with carpet waste co-firing due to the nitrogen content of nylon fiber. In these experiments with shredded fiber and finely ground backing, carpet nitrogen conversion to NO ranged from 3 to 8%. Conversion increased with enhanced mixing of the carpet material and air during combustion. Carpet preparation and feeding method are controlling factors in fuel N conversion.

The use of whole carpets or large carpet fragments should be tested to further evaluate effects of carpet preparation and feeding. Larger carpet waste charges will likely result in lower NO emissions due to reduced conversion of carpet nitrogen content, but may also result in pockets of unburned gas due to rapid volatilization of the carpet.

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ATTACHMENT 2. Correspondence - PaDEP , Roger Fetterling, and Lehigh Cement Co., Peter Smith

Pennsylvania Department of Environmental Protection

**1005 Cross Roads Boulevard**
**Reading, PA 19605-9778**

**Reading District Office**

610-916-0100
FAX: 610-916-0110

Mr. Peter B. Smith
Lehigh Cement Company
7660 Imperial Way
Allentown, Pa 18195-1040

Re: Lehigh Cement Company
Evansville Plant – Carpet Trial
File No. 06-05002
Maidencreek Township, Berks County

Dear Mr. Smith:

I have reviewed your request to conduct a pre-trial test of 20 tons of carpet material in the alternative material handling system and kiln #1 prior to the start of the full-scale carpet trial. This pre-trial as set forth in your letter of May 10, 2004, is approved. The pre-trial run shall be limited to scope as set forth in this letter. Any changes shall be approved by the Department in advance.

This approval is contingent on Lehigh notify the Department of the following:

1. The delivery on site of the 20-tons of carpet.
2. The start of the pre-trial test.
3. The end of the pre-trial test.
4. Any problems or stoppages of the trial.

This approval does not approve the carpet trial as previously proposed by Lehigh. Lehigh shall not accept more than the approved amount of carpet in this letter. No other materials shall be processed during this trial.

If you have any questions concerning this approval, please contact this office.

Sincerely,

Roger A. Fitterling
Air Pollution Control Engineer

cc: File

LEHIGH
HEIDELBERGCEMENTGroup

Lehigh Cement Company
LEHIGH NORTH
7660 Imperial Way
Allentown, PA 18195-1040
Phone (610) 366-4600
Fax (610) 366-4616
www.lehighcement.com

May 10, 2004

Mr. Roger Fitterling
Pennsylvania Department of Environmental Protection
Air Quality Program
Reading District Office
1005 Cross Roads Boulevard
Reading, PA 19605

Dear Roger,

Lehigh Cement Company Evansville requests approval for approximately 20 tons of size reduced carpet material to be used as alternate fuel within the number one cement rotary kiln.

**Pre-Trial Purpose**
The purpose of this pre-trial is to determine if the pilot fuel dosing system can provide mechanical transfer of shredded carpet to the rotary kiln. The pilot fuel dosing system is the same unit the Department saw during the February 11, 2004 site visit. The transfer evaluation is necessary before delivering size reduction equipment and carpet for the actual 1000 ton carpet trial test. If the pilot fuel dosing system cannot provide mechanical transfer of shredded carpet, actual 1000 ton carpet trial will be postponed until a mechanical transfer solution is found.

**Make-up of carpet material** (typical approximate % weight)
50 % nylon, polypropylene or polyethylene face fiber
30 % polypropylene backing
20 % latex adhesive and calcium carbonate filler

Carpet is all post consumer carpet generated from commercial buildings. CarpetCycle, L.L.C. is the provider of the carpet material. Digital photos of the actual carpet will be sent to you tomorrow.

**Timing**
A tractor-trailer from CarpetCycle loaded with post consumer carpet is scheduled to depart for Tennessee on May 12 or 13th of this week. Load will arrive at a facility currently using a shredder manufactured by the same company supplying the shred unit for the 1000 ton carpet trial at Evansville. Scheduled shred will occur Saturday and Sunday May 15 and 16. Once carpet is shredded, load will be shipped directly to Zwicky property and transferred to a walking floor trailer. Mechanical transfer evaluation of the pilot fuel dosing system is planned for the week of May 17th or 24th. Provided the pilot fuel dosing system functions without difficulty, estimated length of pre-trial is 10 hours operating time based on 2 ton/hour carpet feed rate. Operating time may vary based on actual feed rate.

Shipment of carpet scheduled for May 12 will be postponed if Trial Approval is not in Lehigh possession. If May 12 ship date is delayed, the shred facility in Tennessee is not able to reschedule for another three to four weeks. We want to avoid this delay if possible.

Thank you for your consideration regarding this pre-trial.

Sincerely,

Peter B. Smith
Alternate Materials Specialist

Cc: Charles Bortz

ATTACHMENT 3. Approval Letter from PaDEP dated July 7, 2004

Pennsylvania Department of Environmental Protection

**1005 Cross Roads Boulevard**
**Reading, PA 19605-9778**

July 7, 2004

**Reading District Office**

610-916-0100
FAX: 610-916-0110

Mr. Robert Breyer
Lehigh Cement Company
PO Box 619
Blandon, Pa 19510

Re: Trail Run – Carpet Fuel
Lehigh Cement – Evansville Plant
File No. 06-05002
Maidencreek Twp., Berks County

Dear Mr. Breyer:

I have completed the review of your Request For Determination of Requirement for Plan Approval/Operating Permit (RFD) for the proposed trial use of carpet as a fuel in the No. 1 cement kiln. Your April 28, 2004, request involved the firing of carpet in varying amounts in the kiln at your Evansville Plant in Maidencreek Township, Berks County. This letter approves that request as submitted. This approval is contingent upon Lehigh conducting the trial as proposed and meeting the additional requirements below:

1. Lehigh shall determine the emissions of NOx and opacity using the continuous monitors during the trial.
2. Lehigh shall only use that carpet identified in the request.
3. Lehigh shall conduct Method 9 opacity readings of the kiln stack twice per day for the first week of the trial. The results of the readings shall be submitted to this office for review at the end of this period.
4. Lehigh shall maintain records of the fuel usage rates during the trial.
5. Lehigh shall record the temperatures within the kiln during the trial using the existing thermocouples.
6. Lehigh shall only conduct the trial while the emission control system is operating properly.
7. Lehigh shall notify the Department seven days prior to the start of the trial.
8. Lehigh shall notify the Department of the end of the trial and of any problems or stoppages of the trial.

Should you have any questions regarding this approval, please contact me at the Reading District Office, 610-916-0100.

Sincerely,

Roger Fitterling
New Source Review Section
Air Quality Program

cc: Reading