Co-firing of alternative fuels with fossil fuels in the Canadian cement industry

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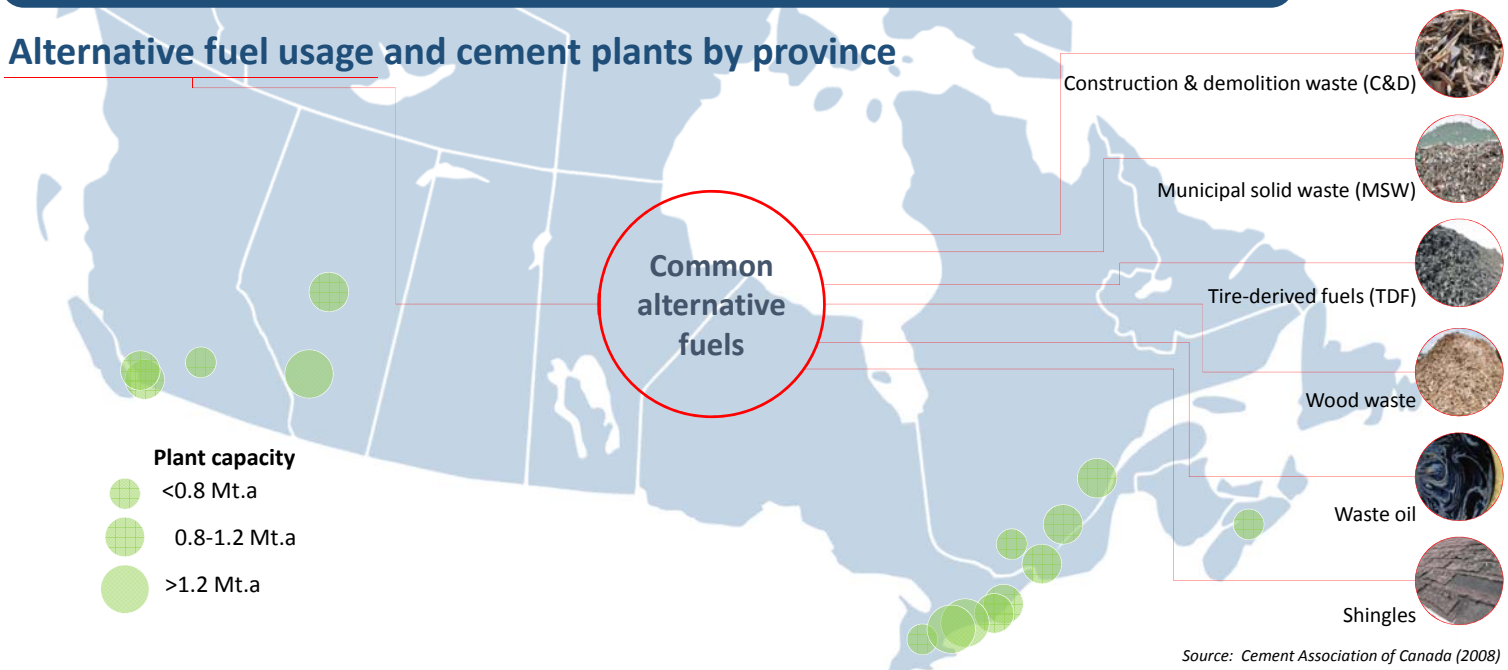
Overview

- Substituting alternative fuels for fossil-based fuels is a **viable approach to reduce greenhouse gas (GHG) emissions**
- Canada's has a low substitution rate can be attributed to the **lack of appropriate policy support** combined with low levels of social acceptance.
- Increasing alternative fuel usage in Canada requires the cement industry to clearly **demonstrate environmental benefits** and develop a communication strategy with stakeholders and the public; the government should set **national standards** characterizing acceptable alternative fuels and outlining quality requirements

Alternative fuel usage and cement plants by province



Source: Cement Association of Canada (2008)

British Columbia
- 2.6 Mt.a clinker
- **9.5%** alternative fuel
- Wood waste, plastics, TDF

Alberta
- 2.4 Mt.a clinker
- **0%** alternative fuel

Ontario
- 6 Mt.a clinker
- **5.3%** alternative fuel
- Waste oil

Quebec
- 3.2 Mt.a clinker
- **34.3%** alternative fuel
- TDF, waste oil, MSW, C&D waste

Nova Scotia
- 0.5 Mt.a clinker
- **8%** alternative fuel
- Waste oil, shingles

- Canada's alternative fuel substitution rate was 10.7% (2012 data), lower than the world average (14.3% in 2012)
- Provincial activities not well coordinated (see table at right)
- Challenges for alternative fuel utilization:
  - Technical and cost issues
  - Procurement issues
  - Regulatory issues
  - Public acceptance
- Canada's coal combustion could be reduced by **350,000 tonnes annually** by increasing substitution rates from 10.7% to 30%
- This is equivalent to **almost 10%** of all emissions related to Canada's cement sector

Province	Key notes
British Columbia	1) Lafarge Kamloops will start to burn coffee cups 2) Lafarge Richmond and Lehigh Hanson both use C&D waste as alternative fuels 3) Lehigh Hanson is on the shortlist of new incineration facilities for Metro Vancouver's municipal waste
Alberta	1) No alternative fuel usage and very little action being taken toward incorporating alternatives 2) Great potential to increase alternative fuel usage as many wastes with energy content are landfilled
Ontario	1) Largest cement producing province with low alternative fuel substitution rate 2) Lafarge Bath and St. Mary's Bowmanville plants are approved to test certain waste materials as alternative fuels and have conducted pilot-scale tests 3) Great potential for using alternative fuels as all plants are close to population centres
Quebec	1) Waste oils, tire-derived fuels (TDFs) are commonly used in Quebec 2) Lafarge Saint Constant has started to burn C&D waste 3) Ciment Quebec and Holcim Joliette each operates a waste disposal and processing facility with the capacity to process up to 50,000 tonnes of waste for use as fuel in their cement kilns 4) Ciment operates a Synergia™ process allowing up to 60% fuel replacement
Nova Scotia	1) Lafarge Brookfield is seeking approval to add non-recyclable plastic to their fuel mix at a maximum substitution rate of 30%

Comparison of moisture probe sensor types on Low Carbon Fuels

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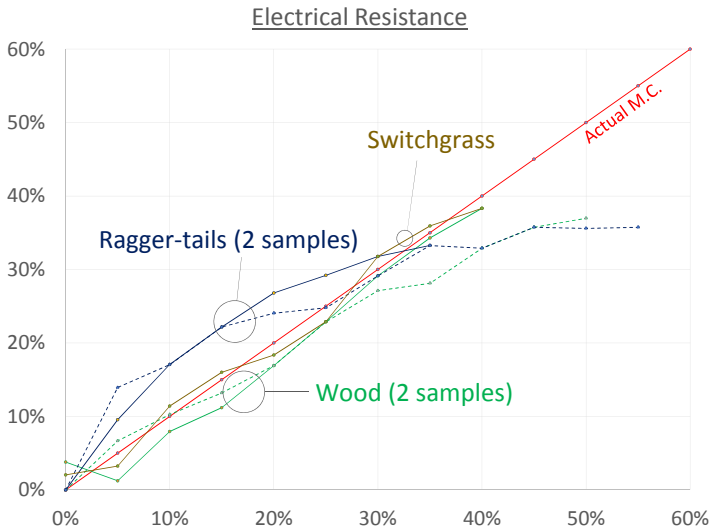
Overview

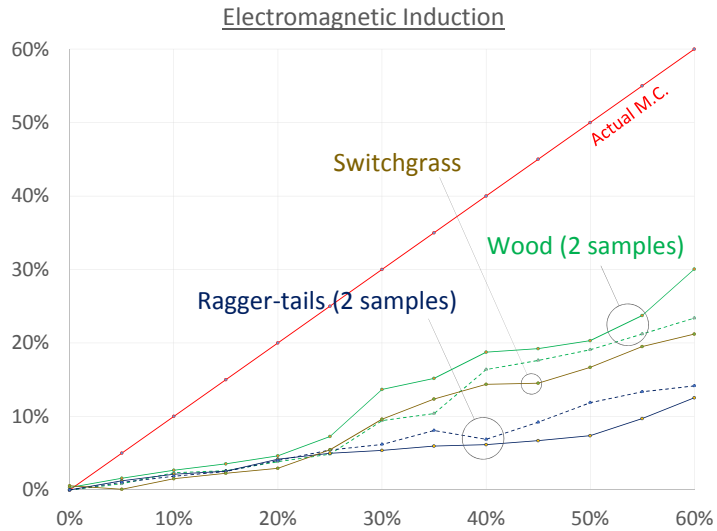
- The focus of this project is to determine **how accurate moisture probes are** when used to analyze the moisture content of low carbon fuels (LCF)
- LCFs tested include construction and demolition (C&D) waste, wood, and asphalt shingles (all currently being used at the Bath Plant), as well as other potential fuels
- This project tells us **which moisture probe technology works best** for each feedstock, as moisture is one of the most important properties affecting energy content of LCFs

Background

- Negative effects due to high moisture content of a fuel are:
  - Decreased energy content
  - Possible alteration to the burners flame shape and flame temperature
  - Increased weight and handling concerns
- Oven-based moisture analysis can take up to 24 hours but are very accurate (used in the laboratory)
- Moisture analysis by moisture probes are instant (better for industrial application) but less accurate

Example of a moisture probe





Moisture contents (M.C.) (%) by two probes, on various low carbon fuels (actual M.C. on x-axis vs. measured M.C. on y-axis)

Outcomes

- Ten probes were considered covering four theoretical approaches: electrical capacitance, electrical conductivity, electrical resistance, and electromagnetic induction (latter two shown above)
- **Electrical resistance probe gave more accurate results** compared to actual moisture content
  - Wood and switchgrass were measured most accurately; probe overestimated ragger-tail M.C.
  - Probe wasn't useful above about 40% M.C.
- **Electromagnetic induction probe vastly underestimated** moisture content for all LCFs tested
- Results indicate that electrical resistance probes are likely the best choice but that no single probe was fully accurate for all LCFs under consideration

A comparison of the stack emissions at the Lafarge Bath cement plant from the combustion of fossil fuels versus a mixture of low carbon fuels and fossil fuels (1 of 2)

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Overview

- This report provided an analysis and evaluation of whether emissions concentrations changed due to the introduction of low carbon fuels (LCF) at the Lafarge, Bath cement plant
- Three LCFs were introduced: construction & demolition (C&D waste, railway ties, and used asphalt shingles
- Key findings from this analysis were that of the 67 parameters considered, only 2 had changes for which further causative analysis is necessary (total suspended particulates, total hydrocarbons)
- Found that **Low Carbon Fuels had no deleterious influences** on the emissions from the kiln

Background

- Stack test data was reviewed using the independent samples t-test statistical test
  - Tested the null hypothesis that the average of the data for any of the test series is the same as the average for any of the other test series
- Four stack tests series considered:
  1. 2014 LCF
  2. 2014 Baseline
  3. 2012 Baseline
  4. 2010 Baseline
- The effect on greenhouse gas emissions was outside the scope of this report

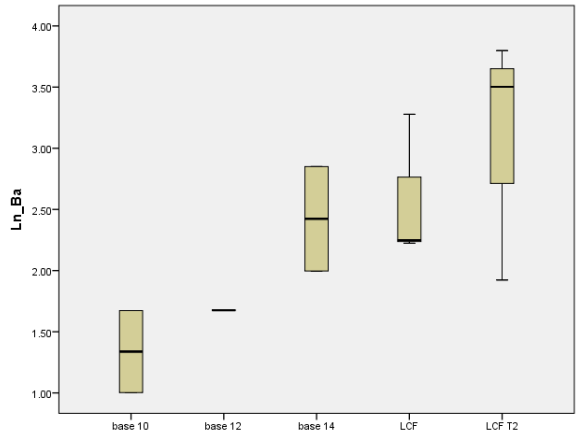
Methods

Five-step approach:

1. Conduct at minimum three stack tests for each series
2. Calculate emissions rates and concentrations to allow comparisons of results
3. Statistically determine where differences are likely not due only to chance and random variability
4. Apply other scientific evidence to screen out statistically determined differences
5. Identify any remaining differences that merit further causative analysis

Example Results: Barium

- Barium identified as having significant t-statistics (2014 v. 2010)
  - Differences between mean values may be significant
  - Mean values:
    - 2014 LCF: 21.64 µg/m^3 @ 11% O_2
    - 2014 Baseline: 12.33 µg/m^3 @ 11% O_2
    - 2012: 5.34 µg/m^3 @ 11% O_2 (2 below detection limit [BDL] value)
    - 2010: 4.03 µg/m^3 @ 11% O_2 (1 BDL value)
- Did the barium values increase from the use of LCF?
  - Two of the 2012 baseline values BDL, no variability
  - No significant t-statistic between 2014 LCF and 2014 Baseline tests, and therefore changes likely due to change in raw materials or facility processes between 2010 and 2014



Conclusions

- LCF substitution had only limited effects on the significance between the means of the emission values
- Since all emissions would meet the most rigorous regulatory emission levels, it can be stated that **LCF substitution had no influence**, deleterious or beneficial, on emissions from the kiln stack

A comparison of the stack emissions at the Lafarge Bath cement plant from the combustion of fossil fuels versus a mixture of low carbon fuels and fossil fuels (2 of 2)

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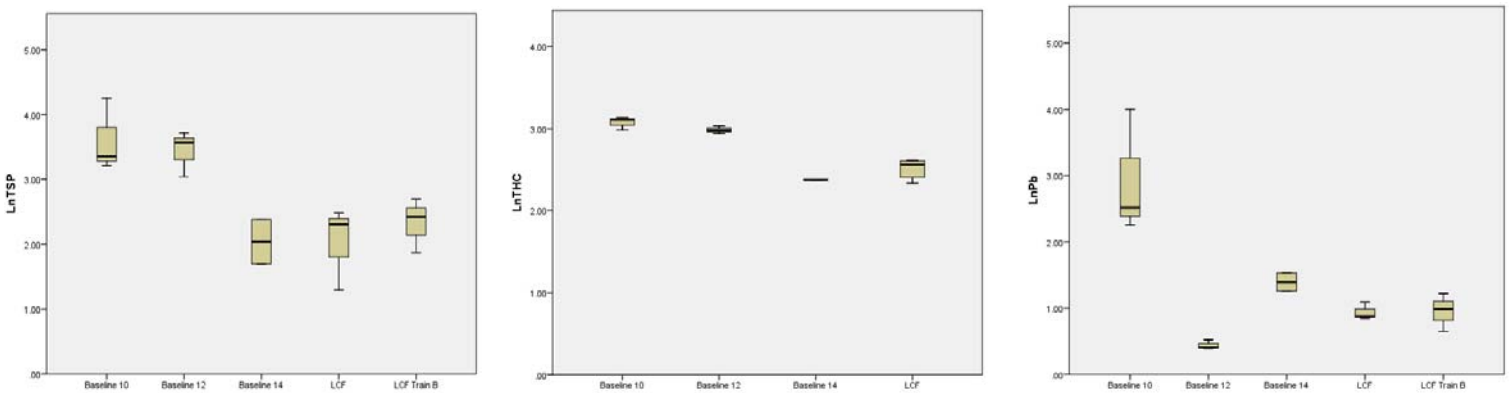
Notable Species

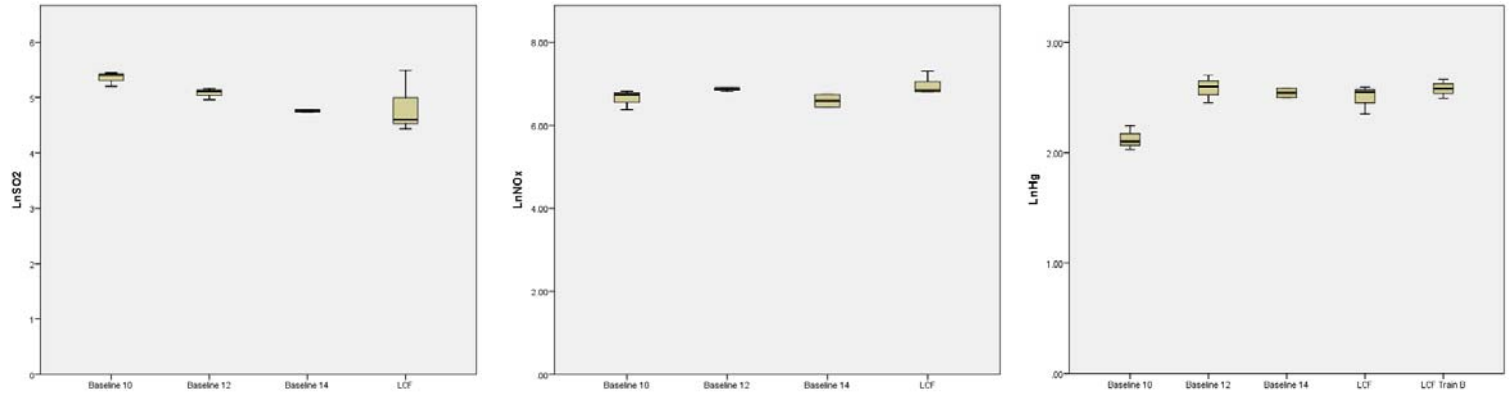
- Dioxin/Furans: It was concluded that there was not a discernable difference between Baseline concentrations and LCF concentrations
- PAH: Various polycyclic aromatic hydrocarbons have increased and decreased between the tests. Changes in raw materials and releases in the pre-heater stage of process likely cause for these differences

Box and whisker plots

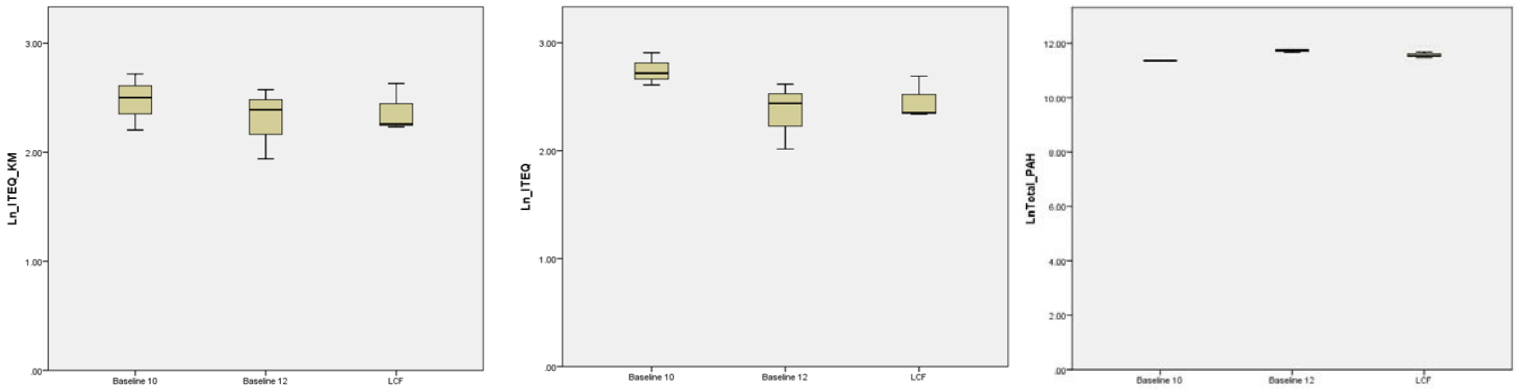
- All plots are corrected lognormally



Figures 1, 2, 3: Box and whisker plots of total suspended particulates, total hydrocarbons, and lead



Figures 4, 5, 6: Box and whisker plots of sulfur dioxide, nitrogen oxides, and mercury



Figures 7, 8, 9: Box and whisker plots of Kaplan-Meier corrected dioxins/furans, dioxins/furans without Kaplan-Meier correction, and total polycyclic aromatic hydrocarbons

Comparative study on the life-cycle greenhouse gas emissions of the utilization of low carbon fuels for the cement industry

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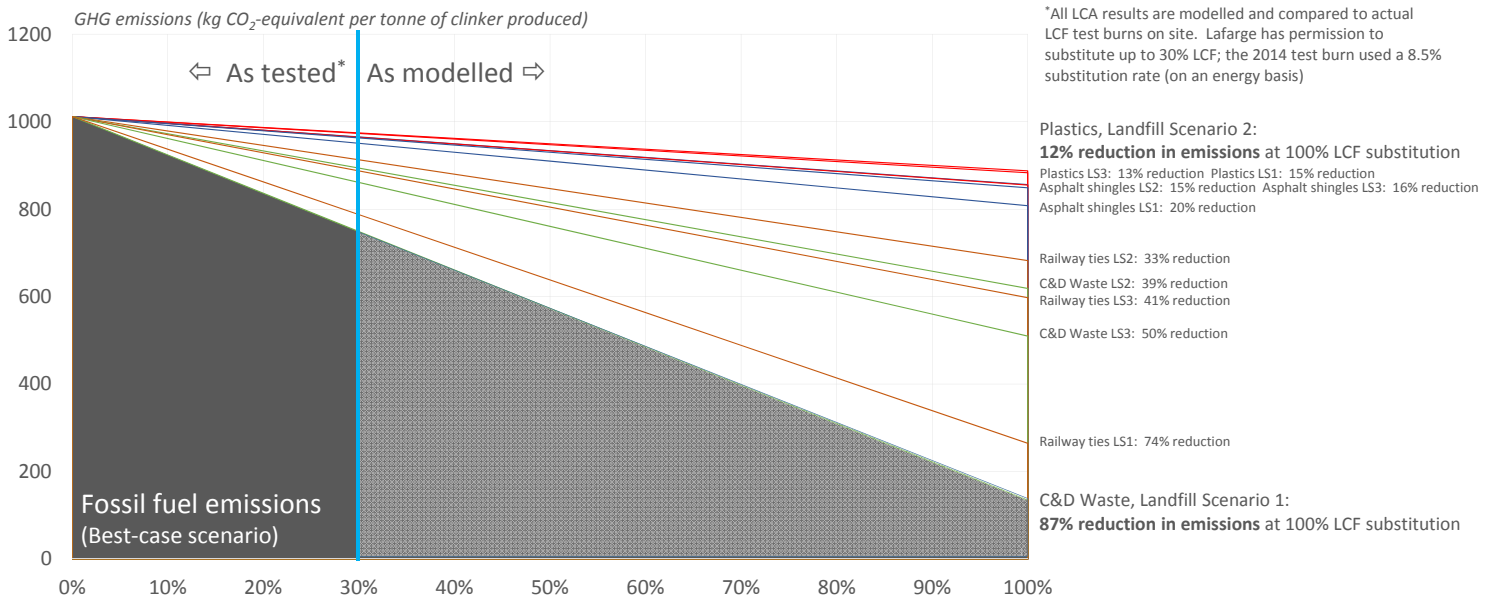
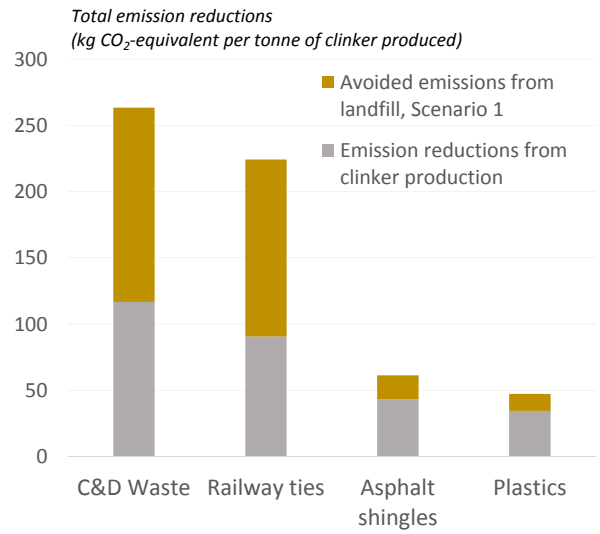
Overview

- This project is developed a life cycle assessment (LCA) model to evaluate the change of greenhouse gas (GHG) emissions by substituting fossil fuels with alternative low carbon fuels (LCF) at the Lafarge Bath plant
- Four **low-carbon alternative fuels (LCFs)** were considered: construction & demolition (C&D) waste, railway ties, asphalt shingles (all tested) and plastics (only modelled)
- Three **landfill options** were considered: Scenario 1 (no flaring or energy generation), Scenario 2 (100% landfill gases flared to reduce methane), and Scenario 3 (75% landfill gas captured and energy produced)
- Best results were found with C&D waste being diverted from a typical landfill with no flaring or energy generation facilities; **up to 87% of emissions** could be avoided if 100% of fossil fuels were replaced with C&D waste diverted from these landfills
- **Real GHG reductions** are expected with **all LCFs** and **all landfill types**



Key findings

- Producing 1 tonne of clinker releases 1012 kg of GHGs, with about 60% GHGs from raw materials and the rest 40% from fossil fuels and electricity
- Lafarge is aiming for a maximum of 30% low carbon fuel by 2020. At this rate of substitution:
  - A **maximum of 26% GHG reduction** can be achieved by switching fossil fuels (coal and coke) to construction and demolition waste), and avoiding C&D deposits at a typical landfill
  - Avoided emissions are also significant with railway ties, but decline significantly with asphalt shingles and plastics (see graphs at right and above)
  - At **30% substitution**, total GHG reduction is equal to **taking 24,600 cars** off the road annually



Alternatives to coal in the world cement industry

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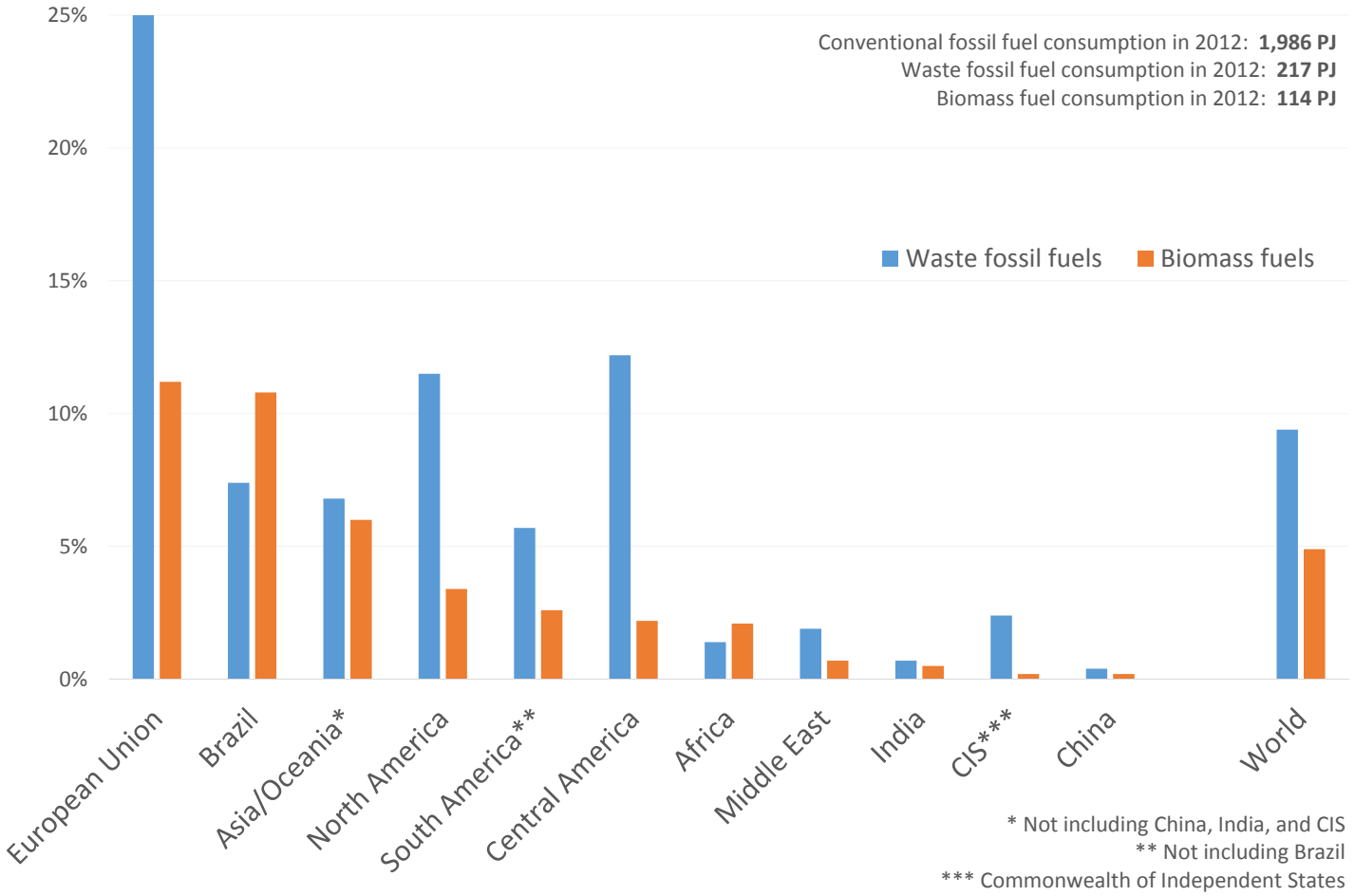
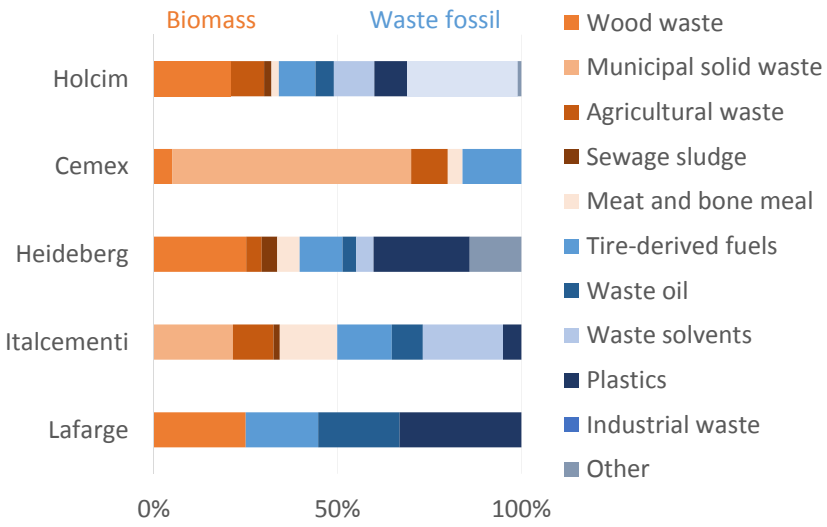
Overview

- Cement manufacturing contributes approximately **5% of global anthropogenic carbon emissions** and uses 7% of global industrial fuel
- A viable option to reduce fossil fuel use and associate emissions is to substitute fossil fuel with alternative fuel sources, either waste fossil fuels or biomass fuels



* Not including China, India, and CIS
** Not including Brazil
*** Commonwealth of Independent States
World Business Council for Sustainable Development – Cement Sustainability Index (2012)

- The average alternative fuel substitution rate was 14.3% - 9.4% waste fossil fuels and 4.9% biomass fuels. The EU has the highest substitution rate (36.2%)
- China produces a high proportion of global clinker, with very little alternative fuel usage
- The use of biomass and fossil-based alternative fuels varies greatly by country and company (see graph at right)
  - Meat and bone meal is widely-used in Europe
  - Sewage sludge is viable but requires drying
  - Wood waste is widely used and imparts a very positive GHG benefit
  - Waste fossil fuels still dominate
- Canada's alternative fuel substitute rate is 10.7% - **well below global average**



Rahman et al. (2015)

Computer simulation of solid particles of low carbon fuel (LCF) combustion within the kiln using computation fluid dynamics

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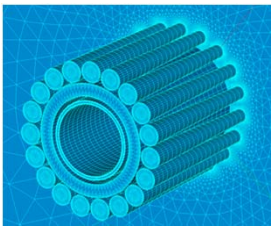
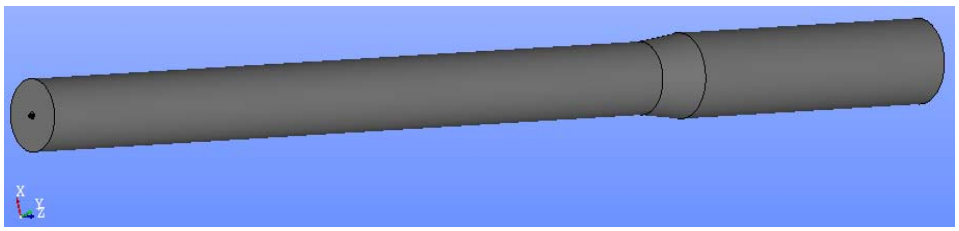
Overview

- This project simulates the movement of solid particles of low carbon fuels injected by air as the carrier to the hot region within a kiln, and the subsequent chemical reactions as a result of the increase in their temperature
- The results will be used to design a **more efficient burner** that produces less nitrous oxides in its operation

Geometry and mesh generation

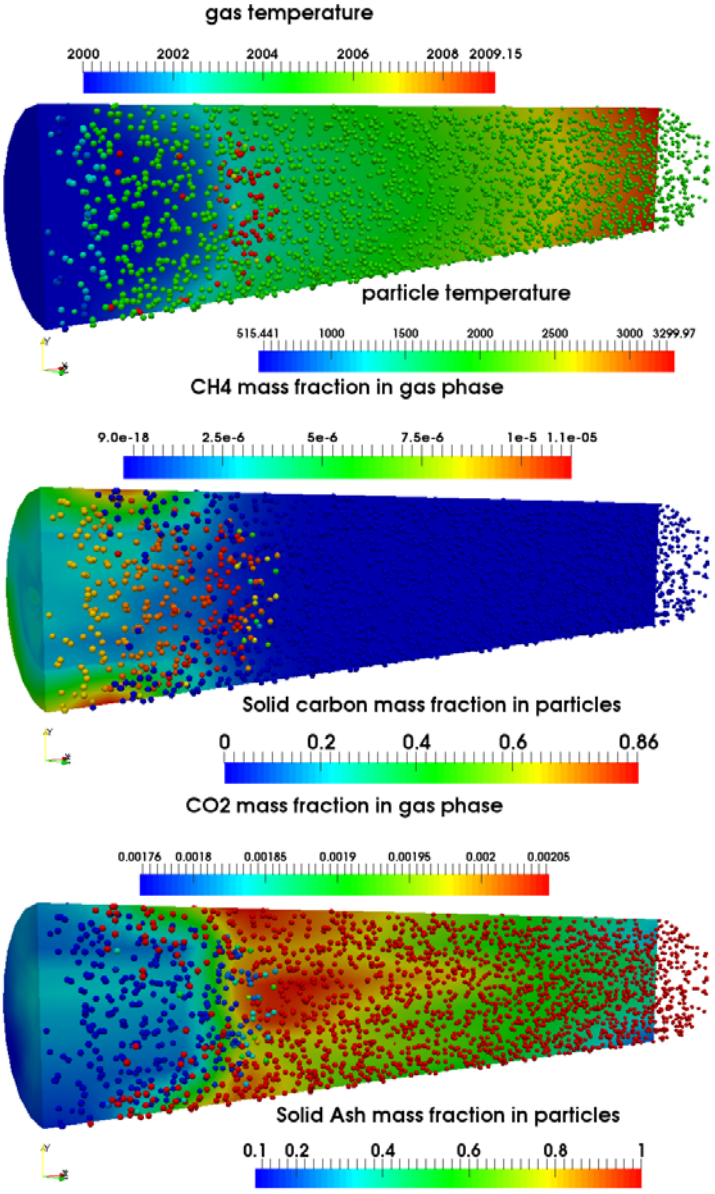
- Typical kiln burner face and meshed burner entrance (right), model (centre), full kiln domain (right)





Physical modeling

- The solid particles are treated as a separate phase interacting with the gas phase which is the air and the combustion products. As a result, the kinematics of solid particles includes:
  - Momentum exchange between particles and gas
    - Due to friction
    - Due to turbulence
    - Due to chemical reaction and mass transfer
    - Due to interaction with walls
  - Calculation of the solid particles trajectories
  - Chemical reactions and heat transfer, including:
    - Temperature increment in solid particles
    - Devolatilization of CH_4 , H_2 and other volatiles
    - Surface reaction of solid carbon with oxygen
    - Combustion of volatiles
  - Heat exchange between the solid and gas phase

Results and future work

- The three goals of the initial phase of work are to:
  - Develop the physical model of particle combustion
  - Validate the results against published data, and
  - Develop the detailed burner and kiln geometry and mesh
- Some results are shown here for a straight pipe with solid fuel injection at the inlet
- CFD package OpenFOAM is used for CFD modelling of combustion and particle tracking within a kiln
- Salome platform is used for geometry and meshing