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Asphalt Roofing Shingles Into Energy Project Summary Report

Owens Corning

Investigation of Asphalt Shingle Use In Energy Recovery And Other Beneficial Reuse Applications

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I. Abstract

Based on a widely cited September, 1999 report by the Vermont Agency of Natural Resources, nearly 11 million tons of asphalt roofing shingle wastes are produced in the United States each year. Recent data suggests that the total is made up of about 9.4 million tons from roofing tear-offs and about 1.6 million tons from manufacturing scrap. Developing beneficial uses for these materials would conserve natural resources, promote protection of the environment and strengthen the economy.

This project explored the feasibility of using chipped asphalt shingle materials in cement manufacturing kilns and circulating fluidized bed (CFB) boilers. A method of enhancing the value of chipped shingle materials for use as fuel by removing certain fractions for use as substitute raw materials for the manufacture of new shingles was also explored.

Procedures were developed to prevent asbestos containing materials from being processed at the chipping facilities, and the frequency of the occurrence of asbestos in residential roofing tear-off materials was evaluated.

The economic feasibility of each potential use was evaluated based on experience gained during the project and on a review of the well established use of shingle materials in hot mix asphalt.

This project demonstrated that chipped asphalt shingle materials can be suitable for use as fuel in circulating fluidized boilers and cement kilns. More experience would be necessary to determine the full benefits that could be derived and to discover long term effects, but no technical barriers to full scale commercial use of chipped asphalt shingle materials in these applications were discovered.

While the technical feasibility of various options was demonstrated, only the use of asphalt shingle materials in hot mix asphalt applications is currently viable economically.

II. Executive Summary

Asphalt roofing shingles have been the predominant materials used in residential roof construction in the United States for many years. Based on a widely cited September, 1999 report by the Vermont Agency of Natural Resources, nearly 11 million tons of asphalt roofing shingle wastes are produced in the United States each year. Recent data suggests that the total is made up of about 9.4 million tons from roofing tear-offs as roofs are replaced and about 1.6 million tons from manufacturing scrap. Most of these wastes are currently disposed of in landfills, and developing beneficial uses for these materials would conserve natural resources, promote protection of the environment and strengthen the economy.

An asphalt roofing shingle contains both organic and inorganic materials. The organic materials (from the asphalt coating, sealant, adhesives, felt, etc.) have potential value as fuel. The inorganic materials (from the granules, limestone filler, backdust sand, glass mat, etc.) have potential value as raw materials for processes that use the various minerals they contain.

This project explored the feasibility of using chipped asphalt shingle materials in cement manufacturing kilns and circulating fluidized bed (CFB) boilers. In both processes, the fuel value of the organic materials in shingle wastes could be realized, and the mineral content would be compatible with the process – perhaps even beneficial. A method of enhancing the value of chipped shingle materials for use as fuel by removing certain fractions for use as substitute raw materials for the manufacture of new shingles was also explored.

Asbestos is no longer used in the manufacture of asphalt roofing shingles in the United States, and therefore scrap from shingle manufacturing does not contain asbestos. However, there is potential for asbestos to be present in roofing tear-off wastes, since some manufacturers used asbestos in roofing materials prior to 1979. As older roofs are replaced, the potential for the presence of asbestos will decrease. Underlayment and mastic materials are more likely to contain asbestos than shingle materials, but separation of these during roof replacement is not practical.

Based on a review of best practices, procedures were developed to identify materials that contained asbestos and prevent them from being further processed for recycling. The frequency with which asbestos was present in loads of roofing tear-off wastes was monitored, and was found to be low – 6 loads out of 355 loads received in 2007. This is in general alignment with results measured in other studies as reported by the Construction Materials Recycling Association (CRMA).

Only materials found to be free of asbestos were processed for use in this project.

To further explore the potential for exposure to fibers from processing roofing tear-off wastes, air sampling was conducted at two processing facilities. All total fiber results measured were below OSHA's 8-hour time-weighted average (TWA) permissible exposure limit (PEL) for asbestos, none of the fiber samples showed any asbestos fibers, and all respirable particulate and crystalline silica results were non-detectable and well below their respective OSHA PELs.

Given the potential for a cement kiln to utilize large quantities of chipped shingle wastes, materials could conceivably be sourced from a wide area of several processors. In order to address concerns that asbestos containing materials might pass through the testing and rejection protocol at the processing center, tests were conducted to determine whether asbestos would survive in the cement kiln system.

Results showed that asbestos would not survive processing in a cement kiln. The asbestos fibers undergo an irreversible conversion into a new crystalline phase, losing their hazardous characteristics.

The project plan called for a full scale trial using chipped shingle materials at an operating cement manufacturing facility. Given the difficulties in obtaining permissions for such a trial from regulators and the potential disruption in production, a pilot scale study was first conducted to evaluate potential emissions and effects on cement quality. Shingle materials, both from tear-offs and from manufacturing scrap, were fed into a pilot scale calciner vessel with raw meal feed from a cement plant. Emissions were measured and the impacts on the process solids from the calciner were evaluated.

No barriers to conducting a full scale trial at a cement plant were discovered in the pilot test; however the several cement manufacturing locations considered for a trial were not sufficiently motivated to conduct a trial. Difficulties in permitting combined with the presence of more attractive business alternatives prevented further development of a trial. Nevertheless, the pilot testing confirmed that the shingle materials are compatible with the cement manufacturing process.

A trial was conducted using processed roofing tear-off materials at a small CFB boiler producing steam for institutional domestic hot water and heating purposes. The trial demonstrated the technical feasibility of this application, showing improvements in SO_2 and NO_x emissions and improvements in the stability of the boiler.

CFB boilers typically use limestone along with their fuel to control SO_2 emissions. Potential exists to reduce limestone consumption by using shingle materials as fuel, however this potential could not be completely evaluated during this trial.

In order to enhance the value of shingle wastes, chipped shingle materials were sieved to separate various fractions. The coarser materials (retained on a #12 sieve) were high in organic content and more suitable for use as fuel. Materials finer than the #12 sieve but coarser than the #20 sieve were potentially suitable for use as alternative headlap granules in the manufacture of new asphalt shingles. The materials finer than the #20 sieve were potentially suitable for use as alternative filler and asphalt for new asphalt shingles.

The separation of materials was effectively accomplished on roofing tear-off materials, but the nature of the fresh asphalt in manufacturing scrap prevented the desired separation from this material stream. Thus, this separation was found to be feasible only on tear-off wastes.

The evaluation of these separated streams showed that the separation enhanced the fuel value of the organic fraction from a range of about 5,000 to 6,000 BTUs per pound to a range of about 6,000 to 8,000 BTUs per pound. The use of the granule fraction as alternative headlap material was shown to be technically feasible in a full scale trial when recycled granules are mixed with new granules (about 85% new with 15% recycled).

Testing showed that the finer fraction has potential for use as an alternative for filler and asphalt in new shingle manufacturing, however conducting a full scale trial would require substantial capital investment due to the challenges associated with handling filler material containing asphalt. Existing equipment and processes cannot handle this material without significant modification.

From an economic standpoint, the various uses for shingle wastes (cement kilns, CFB boilers and new shingle manufacturing) are not currently viable. Cement kilns expect to be compensated for the permitting and processing challenges associated with additional fuel streams. CFB boilers typically burn cheap coal from waste coal stockpiles, and unless limestone consumption can also be reduced, transportation costs would reduce the economic viability of most projects. Use of the granular portion of tear-off wastes as a substitute for headlap granules is expensive due to the need to blend recycled granules with standard granules and ship them to the manufacturing facility.

The use of both shingle manufacturing scrap and roofing tear-off wastes in hot mix asphalt (HMA) production is a promising application. Virgin asphalt used in HMA is increasingly expensive, currently at about $350 to well over $400 per ton. HMA producers operate in a very competitive, regional market, and there is sufficient economic incentive to utilize shingle materials for both the asphalt they contain and their value as an aggregate.

Many states (11) have state DOT specifications allowing the use of shingle materials in HMA, and the American Association of State Highway and Transportation Officials (AASHTO) has developed a provisional specification for the use of recycled asphalt shingles.

In addition to the widespread acceptance of shingle materials in HMA, a local infrastructure of contractors, haulers, processors and pavers is already established in many areas. Further development of this market would conserve resources, aid in the protection of the environment and have positive economic impact for homeowners, contractors and businesses.

III.Project Description

A. Problem Statement

Asphalt roofing shingles have been the predominant material used in residential roof construction in the United States for over 60 years. Their relatively low weight per square foot covered, ease of installation and excellent performance have resulted in the widespread adoption of asphalt roofing shingles in the US residential roofing market.

The performance lifetime of an asphalt shingled roof varies depending on the weather conditions, installation methods and quality of shingle used. According to data reported by the National Association of Home Builders (NAHB), the average age of asphalt shingled roofs replaced in 2006 was about 18 years old. About 3.5 million homes in the United States are re-roofed each year, producing an average of 3 to 4 tons of tear-off waste per home. In the US, approximately 9.4 million tons of residential roof tear-off wastes are generated each year.

In addition to roof tear-off wastes, shingle manufacturing generates approximately 1.6 million tons of waste shingle materials from cutouts, torn sheets or substandard products.

The bulk of these waste streams totaling about 11 million tons per year are currently disposed of in landfills, consuming millions of cubic yards of landfill space each year. Once landfilled, compaction of the materials is difficult and degradation is limited.

In addition to the consumption of landfill space, disposal of asphalt shingle wastes squanders the value of the minerals, fibers and asphalt in the materials. The typical composition of an asphalt shingle, depending on type and manufacturer, is as follows:

Asphalt coating	16 - 25%
Mat	2 - 15%
Granules	28 - 42%
Filler	32 - 42%
Backdust	3 - 6%

The organic components of roofing tear-off wastes, including the asphalt coating, sealants, adhesives and underlayments, have fuel value. The inorganic components, including glass mat, granules, filler and backdust, have potential value as raw materials for processes that use the various minerals they contain.

Finding beneficial methods of recycling or energy recovery from roofing wastes would not only reduce the amount of waste landfilled, but would also conserve resources by providing alternative fuel to replace fossil fuels, reducing the amount of raw materials needed for manufacturing products that use the various components contained in the wastes and potentially reducing the energy required to process virgin raw materials.

The Construction Materials Recycling Association (CMRA) has published two excellent resources entitled “Recycling Tear-Off Asphalt Shingles: Best Practices Guide” and “Environmental Issues Associated With Asphalt Shingle Recycling” which may be obtained from the CMRA or downloaded from their web site at www.shinglerecycling.org.

In addition to the environmental and resource conservation benefits of recycling asphalt shingles, development of recycling alternatives would have a positive economic impact on our society by providing cost effective alternatives for roofing contractors and providing new growth opportunities for independent businesses.

B. Project Goals - Areas Investigated

The premise of this project was that recycled residential asphalt shingles have inherent energy and raw material value in select applications. A further premise was that the occurrence of asbestos in residential roofing tear-off wastes is infrequent, and that testing could eliminate the risk of asbestos being accepted into the recycling process.

The use of asphalt roofing shingle wastes in the production of hot mix asphalt for paving has been ongoing for some time. This project explored the potential to use these waste materials in other valuable applications where the fuel value and mineral value might be realized, such as in cement kilns or circulating fluidized bed (CFB) boilers.

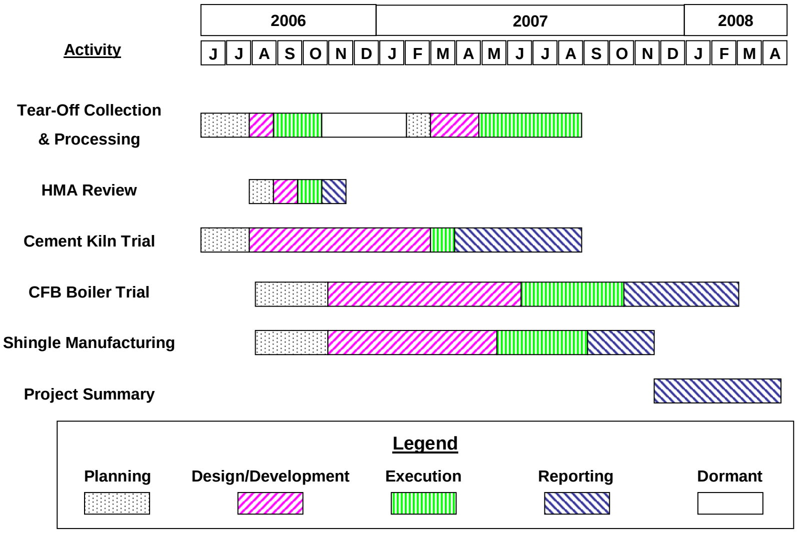
The initial goals of the project were as follows:

1. Determine the frequency with which asbestos is present in roofing tear-off wastes and develop the ability to test for its presence in a particular waste stream;
2. Review the use of shingle materials in hot mix asphalt production;
3. Determine the feasibility of using asphalt shingle wastes from manufacturing and from roofing tear-offs in the manufacturing of Portland cement;
4. Better understand the thermal degradation of asbestos at high temperatures such as exist in cement kilns; and
5. Better understand the economic feasibility of recycling asphalt shingle wastes.

As the project proceeded, the scope was amended to also consider the use of asphalt shingle materials in CFB boilers. In addition, while exploring methods of enhancing the fuel value of the materials by separating the organic and mineral fractions, the amended scope also considered the use of certain portions in the manufacture of new asphalt shingles.

C. Project Activities

A project plan was developed to address each of the project goals listed above, and an approximate timeline of major project activities is shown in Figure 1. The planned approach was to demonstrate the technical feasibility of using chipped asphalt shingle materials as fuel in cement kilns by conducting a trial at an operating cement manufacturing facility. As materials were prepared for use in the trial, the frequency of the occurrence of asbestos in residential roofing tear-off wastes was monitored by testing materials being brought into the processing facility. A review of best practices regarding asbestos identification and testing was made in order to insure that asbestos containing materials could be properly identified and rejected to avoid further processing.



Approximate Project Timeline
Figure 1

Cement kilns were chosen for study because of their need for fuel and the compatibility of the inorganic mineral components of the shingle materials with the cement manufacturing process. It became apparent that shingle materials were also compatible with CFB boilers using limestone for SO_2 emissions control, and the project scope was amended to include a trial demonstrating the use of chipped shingle materials in a CFB boiler.

In order to assess the comparative value of using shingle materials in cement kilns and CFB boilers, a review of the well established use of these materials in HMA was conducted. The recycling contractor processing shingles and roofing wastes was asked to estimate the costs associated with testing and processing the materials based on the experience gained during the trials.

As discussed in a later section, a full scale trial at a cement plant was not able to be performed. A pilot scale test feeding materials into a calciner vessel and monitoring the impact on emissions and process solids from the calciner was conducted to discover any barriers to a full scale trial. No barriers were found, however the several cement manufacturing locations considered for the trial were not sufficiently motivated to conduct a trial given the difficulty in obtaining the appropriate permits, especially while more attractive business opportunities exist.

Difficulties were encountered while conducting the CFB boiler trial, limiting the amount of useful data that could be obtained. An evaluation of the impact of using shingle materials on limestone consumption in the CFB boiler could not be made, but the trial did confirm the compatibility of shingle materials with the CFB boiler operation.

In order to explore the potential to enhance the value of shingle materials for use as fuel, trials were conducted separating the inorganic mineral fraction from the organic fraction. This created an opportunity to evaluate the use of certain fractions with little fuel value for use in the manufacture of new asphalt shingles. The amended project scope included this evaluation as well.

Despite the limitations of the trials conducted, valuable experience was gained on which the conclusions of this report are based.

IV. Results

A. Asbestos

1. Summary

Since asbestos is no longer used in the manufacture of asphalt roofing shingles in the United States, modern manufacturing wastes do not contain asbestos. However, some manufacturers used asbestos as reinforcement in shingles prior to 1979. Some underlayment materials and mastics may also contain asbestos, but these are more commonly found in commercial roofing. Roofing products containing asbestos are rarely used in residential roofing.

Available literature suggests that, when used in the manufacture of asphalt roofing shingles, asbestos comprises less than 1% of the shingle by weight. Underlayment materials manufactured with asbestos contain from 10 to 15% asbestos, and mastics produced with asbestos contain from 5 to 25% asbestos (US EPA Purple Book, 1985).

The occurrence of asbestos in residential roofing tear-off wastes is relatively infrequent. According to case studies conducted from 1994 through 2007, of 27,694 samples taken, 1.53% were found to contain detectable amounts of asbestos, mostly from mastics, not from the shingles themselves (Environmental Issues Associated With Asphalt Shingle Recycling, Construction Materials Recycling Association, October, 2007).

For the purposes of this project, only waste streams that were determined to be free of asbestos were accepted for further processing and use in the various trials. Roofing tear-off materials arriving at the processing center were sampled and tested for the presence of asbestos. Every tear-off load from which any sample indicated the presence of asbestos at any concentration was rejected from further processing and was disposed of in accordance with applicable regulations.

Experience gained in screening roofing tear-off waste streams for the presence of asbestos suggests that the tests can be practically applied in the field through the use of standard operating procedures that insure proper sampling, material handling and the use of adequate PPE (Personal Protective Equipment). The procedures must include contingency plans to insure that regulatory and proper disposal requirements are met in the event that materials are found to contain asbestos.

2. Issues

Processing of roofing tear-off materials may include dumping, sorting, chipping and sieving. Whether or not the encapsulation of asbestos by the asphalt binder in roofing materials sufficiently reduces the hazards associated with asbestos exposure is a matter of discussion among experts. Thus, in order not to increase the potential for exposure of workers to asbestos at the processing center, incoming loads were quarantined pending the results of testing the samples. Only materials found to be free of asbestos were further handled and processed for use in the trials conducted.

EPA Method 600/R-93/116 was used to test roofing tear-off materials for the presence of asbestos. Normal turnaround time for test results is about 4 days. This delay was found to require a significant amount of storage space in order to hold materials pending the test results. One alternative being used by processors is to have laboratory facilities at the processing center with appropriately trained personnel to run the tests on-site.

3. Technical Feasibility

A search was conducted to determine the best practices available to insure that asbestos containing materials could be identified and handled properly. However, this project did not investigate the technical feasibility of using roofing tear-off wastes containing asbestos in recycling or energy recovery projects. Only materials found to be free of asbestos were processed for use in the trials conducted.

Chipping of the shingle materials is normally accomplished using a high speed hammermill. During the processing of shingles at two recycling facilities, air sampling was conducted to determine the amount of total and respirable fibers to which workers might be exposed. Results showed that

- All total fiber results measured below OSHA's 8-hour time-weighted average (TWA) Permissible Exposure Limit (PEL) for asbestos of 0.1 f/cc
- None of the fiber samples analyzed by TEM showed any asbestos fibers
- All respirable fiber samples measured below the 8-hour TWA value of 0.05 f/cc for durable respirable fibers
- All respirable particulate & respirable crystalline silica results were non detectable & well below their respective OSHA PELs.

Of 355 loads of tear-off materials received at the processing center in 2007, six (1.69%) were found to contain a detectable amount of asbestos using EPA Method 600. This is in alignment with experience in other studies as mentioned above.

Experience gained during this project using EPA Method 600 suggests that screening roofing tear-off waste streams for the presence of asbestos is technically feasible, provided that:

- Contractor and processor personnel can be adequately trained to recognize different types of roofing materials in loads of tear-off wastes;

- Loads of tear-off wastes from different sites of generation are not combined prior to testing;
- Only materials from residential tear-offs are accepted. (Materials from commercial or industrial sites are more likely to include asbestos containing materials.);
- Proper handling techniques and PPE are used in proximity to untested materials;
- A sample of each type of shingle, underlayment and other roofing material present in each load is taken and tested independently (not composited);
- Loads are staged separately until testing results are obtained;
- A plan is in place and implemented that will insure that materials found to contain asbestos are sequestered, stored and disposed of in accordance with all applicable EPA, OSHA and other rules and regulations, including proper recordkeeping.

This project demonstrated that sampling and analysis of tear-off wastes using the above procedures on materials prior to processing is adequate to insure that the processed materials are free of asbestos. In all cases, testing of the materials after processing (chipping, sieving, etc.) showed no detectable asbestos.

B. Use in Hot Mix Asphalt (HMA)

1. Summary

Approximately 500 million tons of hot mix asphalt (HMA) pavement is produced in the United States each year. The use of asphalt roofing shingle wastes in the production of HMA has been ongoing for some time, and a substantial body of experience shows that pavement can be produced with up to 5% asphalt roofing shingles with no adverse effect on quality. Due to the amount of asphalt they contain, the use of asphalt roofing shingles in the production of asphalt pavement can allow a reduction in the virgin asphalt content from about 5% of the HMA mix to about 4% of the mix.

2. Issues

Generally, the asphalt content of asphalt shingle waste is harder and stiffer than virgin asphalt used to product HMA for pavements. Therefore, some adjustments must be made in mix designs to accommodate the shingle materials. In addition, some adjustments to pavement compaction procedures may be necessary.

This increased stiffness is particularly characteristic of roofing tear-off wastes where the asphalt is more oxidized, and mix adjustments should be evaluated for each stream used. Alternatively, streams may be blended together in a batch stockpile, and mix adjustments made for each stockpile.

Use of shingle materials in HMA applications generally requires chipping to a top size of about ½ inch. While somewhat coarser material may be used for base courses, the materials generally perform better as they are more finely chipped.

3. Technical Feasibility

The use of asphalt shingle materials in HMA applications is well known, and the technical feasibility has been well demonstrated. HMA applications represent the largest current use for shingle tear-off and manufacturing wastes. As stated above, up to 5% of the HMA mix can be made up of chipped asphalt shingle materials with no adverse effect on quality.

The American Association of State Highway and Transportation Officials (AASHTO) has developed a provisional specification and recommended practice for shingle recycling into HMA, and, as shown in the table below, several state departments of transportation have material specifications for the use of shingle materials in HMA.

State	**Dept of Transportation (DOT) Specs**	**Beneficial Use Determination License (BUD) Approvals**
DE		BUD for M Scrap
IN	5% M Scrap Only	
NC	5% M Scrap Only	
NJ	5% M Scrap Only	
PA	Provisional Spec c04031A	
TX	M Scrap Only	
VA	Special Provision	
CT		General BUD permit for recycling and storage of tear-off scrap
GA	5% M or T Scrap	
MA	5% M Scrap	BUD for M or T scrap
ME		BUD for T scrap
MN	5% M or T Scrap	BUD permit by rule for M & T Scrap
MO	5% M or T Scrap	
NY		BUD for M or T Scrap
SC	3-8% T Scrap	
FL	Under Development	

Source: US EPA & CRMA
M Scrap refers to manufacturing scrap
T Scrap refers to roofing tear-off wastes

States With DOT Materials Specs For Shingle Materials in HMA
And/Or Beneficial Use Determination Approvals
Table 1

Several technical reports and case studies regarding the use of shingle materials in HMA can be found at www.shinglerecycling.org, the web site of the CMRA devoted to asphalt shingle materials.

As discussed in a later section, the feasibility of the use of shingle materials in HMA applications is limited by the local availability of properly processed materials.

C. Use in Cement Manufacturing

1. Summary

Portland cement is manufactured by processing limestone, silica, alumina, iron and other trace elements at extremely high temperatures to the point of fusion in rotating kilns. At these high temperatures, the proper minerals are formed to give cement its hydrating properties. The minerals are formed into a nodule called a clinker by the tumbling action in the kiln. The resulting clinker is finely ground with other additives to form the grey powder called Portland cement.

Achieving the high temperatures necessary to form clinker requires over two million BTUs per ton (2,326 kj/kg) of clinker produced, depending on the equipment and materials being used. Coal is the primary fuel being used in cement manufacturing, and the industry is seeking alternatives to achieve lower costs and fewer emissions.

Given the need for both fuel and minerals to produce Portland cement clinker, cement kilns may be well suited for the use of asphalt shingle materials. In fact, the industry has some limited experience using chipped asphalt shingle materials without detrimental effects on the process or cement product quality.

Several cement manufacturing locations were contacted in order to determine an appropriate site for testing the use of shingle materials in cement kilns. Due to a variety of logistical, process and regulatory constraints, a full scale trial was not able to be conducted.

In order to gather data to address the process and regulatory concerns of cement manufacturers, a test was conducted in a pilot scale calciner vessel. Three types of shingle materials were fed into the calciner with the raw feed materials from a cement plant with a preheater kiln system. Emissions, calciner product and baghouse fines were evaluated for the following feed combinations:

- Baseline using cement raw material feed (raw meal) only,
- Raw meal plus roofing tear-off wastes chipped to a top size of about $^3/_8$ inch,
- Raw meal plus shingle manufacturing waste chipped to a top size of about $^3/_8$ inch,
- Raw meal plus roofing tear-off wastes chipped to a top size of about $^3/_8$ inch and screened to remove most of the granules.

A report describing the testing and results is included as Appendix A.

2. Issues

The rotary kiln system used to produce Portland cement clinker is a continuous, dynamic process involving many variables. Perhaps the most important factor affecting clinker quality and cost of production is the stability of the process. Therefore, a large amount of effort is put into maintaining this stability. Uniformity of feed chemistry and fuel chemistry are important criteria. Consistency in the thermal profile of the system and in the gradation of feed and fuel materials is likewise important. Variations cause upsets in the balance of the process and adversely affect both product quality and cost of production.

A key issue for the use of shingle materials in kilns then is to insure uniformity in chemistry, fuel value and gradation. Where variations are unavoidable, care must be taken to compensate for them by adjusting other process parameters.

For roofing tear-off wastes, blending of streams into larger stockpiles to reduce variations may be necessary, but would need to be evaluated on a case-by-case basis. The testing performed during the pilot test was not sufficient to evaluate the range of variation in the concentrations of the various constituents of interest for cement kilns (e.g. metals, chlorine, sulfur, alkali, heat value, etc.).

Aside from consistency and uniformity of the shingle materials, a key concern of the cement kiln process is the determination of the appropriate point of introduction into the system. While the industry has some experience using waste fuels inserted in the riser duct or onto the feed shelf of preheater kilns, there are concerns about unburned fuel entering the material bed and causing localized reducing conditions, which adversely affect product quality. In addition, some experience burning waste fuel in these areas has resulted in unacceptable build up of residues.

In the pilot scale calciner, shingle granules dropped out of the gas flow and collected in the bottom of the unit. Therefore, when selecting a point for introducing these materials into a full scale system, consideration should be given to the effect granule drop-out may have on the process.

The chemistry of materials and fuels fed to the kiln system is another key issue of concern for cement manufacturers. While cement kilns have an extremely high destruction efficiency with regard to organic compounds, emissions metals and dioxins and furans are of particular concern to cement manufacturers. The concentrations of metals in the clinker produced by the kiln are also important.

The concentration of metals in chipped shingle materials was similar to the range of concentrations found in various coals used as fuel for cement kilns. The concentrations of chromium (Cr), nickel (Ni), lead (Pb) and zinc (Zn) were found to be higher in roofing tear-off materials than in the raw meal or shingle manufacturing waste, and the concentration of copper (Cu) was found to be higher in shingle manufacturing waste than in tear-off wastes or in the raw meal. Since the testing was being performed on a pilot scale calciner, natural gas was used as the primary fuel. The concentrations of metals were monitored in the emissions, in the product from the calciner and in the baghouse fines. Dioxin and furan emissions were monitored as well as emissions of SO_2, NO_x, HCl and total hydrocarbons.

Measured metals concentrations were acceptable, however some differences from the baseline condition could not be explained by the differences in feed to the system. Due to the physical configuration of the test equipment, mass feed rates could not be measured closely enough to conduct mass balances to determine the source and fate of the metals.

While no emissions results from the pilot unit were problematic for a cement kiln from a compliance standpoint, results for some pollutants varied unexplainably during the test period. As described in the detailed report in Appendix A, it appears that most of these variances were not related to the shingle feed material. In most cases, the statistical significance of the differences in emissions compared to the baseline emissions was less than 95% (the confidence level commonly used by EPA). Very few emissions of dioxins and furans were detected, and the maximum possible emission calculated from the detection limits was orders of magnitude lower than the MACT limit applicable to cement kilns.

There was an unexpected, statistically significant increase in NO_x emissions while using shingle materials, and the cause of this increase is not clear. It should be noted, that NO_x emissions from a cement kiln system are primarily from thermal formation and from fuels. Changes in NO_x emissions would be highly dependent on the configuration of the system and the ratio of fuels being utilized at the various firing points. Therefore, the increase in NO_x emissions measured during the pilot test should not be extrapolated or generalized to conclude that a similar increase would be expected in a full scale system.

Given the large amount of shingle materials that could be consumed by a cement kiln, it was anticipated that the materials at a given kiln would come from a variety of sources covering a broad area. Research was conducted to determine the fate of asbestos in the event that asbestos containing materials somehow made their way through the testing and control procedures at the processing centers.

Based on available literature and knowledge of the properties of asbestos, it was concluded that asbestos cannot survive the thermal conditions of a cement kiln and would undergo an irreversible conversion to a non hazardous material.

In order to confirm the hypothesis developed in the study, laboratory testing was jointly designed and conducted by nationally recognized experts from the field of asbestos study and the field of cement kiln processing. To simulate the conditions to which asbestos would be subjected in a cement kiln, chrysotile asbestos, the only type ever used for making asphalt shingles, was heated to 1,000 ^{o}C for twenty minutes. Mixtures of cement kiln feed and 7% chrysotile asbestos, and post consumer asphalt roofing shingles and 7% chrysotile asbestos were also heated to 1,000 ^{o}C for twenty minutes. After heating, the materials were analyzed using powder x-ray diffraction to detect crystalline phases present. A sample of shingle and 7% chrysotile asbestos was also heated to 1,400 ^{o}C and likewise observed for crystalline phases. Note that a concentration of 7% asbestos (a level much higher than what would be expected when asbestos is found in roofing tear-off wastes) was utilized to insure detection by the equipment used in the test.

Tests confirmed that regardless of whether asphalt shingles or cement kiln feed are present, asbestos does not survive the heating regimen to 1,000 ^{o}C or 1,400 ^{o}C. As expected, asbestos loses its asbestos properties and undergoes an irreversible conversion to a different crystalline phase at these elevated temperatures, losing its hazardous characteristics. A detailed report of the research and laboratory testing is included in Appendix B.

3. Technical Feasibility

Both the pilot testing and cement industry experience with shingle materials have demonstrated that the use of roofing tear-off wastes and shingle manufacturing wastes in cement kiln systems is technically feasible. While the pilot test was not able to fully simulate a kiln system, the data collected suggest minimal impact on emissions and on parameters affecting product quality. No barriers to conducting full scale commercial trials at operating cement plants were found.

Technical feasibility at a particular cement plant would depend upon:

- The physical configuration of the equipment and the determination of a suitable point of introduction of shingle materials to the system,
- The chemistry of the raw materials and other fuels being used,
- The ability to blend shingle materials sufficiently to avoid unacceptable variations in chemistry and fuel value, and
- Regulatory and permitting requirements.

As discussed in the section on economic feasibility, a full scale trial was not conducted due to a lack of sufficient economic incentive for the cement manufacturer to accept the challenges associated with permitting and with adapting the process to the use of shingle materials.

D. Use in CFB Boilers

1. Summary

Circulating fluidized bed (CFB) boilers can be designed to accommodate a wide variety of solid fuels. In the combustion chamber, fuels are introduced into a stream of upwardly flowing air. The upward velocity of the air suspends the fuel as it burns and carries the heat upward to a heat exchanger. As the fuel burns, smaller particles are carried upward with the gas flow, through a separator and circulated back into the combustion chamber. Fine ash is removed from the gases prior to exhaust.

Emissions of SO_2 are typically controlled by the addition of ground limestone with the fuels. NO_x emissions are controlled by maintaining a stable, uniform bed temperature.

A trial was conducted to determine the feasibility of using tear-off wastes in CFB boilers used to produce steam for the domestic heating, cooling and hot water supply for an institutional facility. The boiler operation included two identical boilers, each capable of producing 15,000 lbs of steam per hour. One boiler was typically on line while the other was held in reserve in case of an outage. Bituminous coal waste with a sulfur content of less than 1.2% was burned as the primary fuel.

A small scale trial conducted in August of 2006 suggested that recycled asphalt shingles could be substituted for up to 20% of the coal waste without adverse effects on the operation or emissions of the boiler. In fact, the results showed a significant improvement in SO_2 emissions, and boiler stability improved as well.

During the period of June through October of 2007, a full scale test was conducted using chipped shingle materials for up to 40% of the total fuel by weight. Two types of shingle tear off waste materials were evaluated. Both tear off wastes chipped to a top size of about one inch and tear off wastes chipped to a top size of about $^3/_8$ of an inch and sieved to remove most of the granules performed well in the fluidized bed. Consistent reductions in SO_2 and NO_x emissions were noted, and the stability of the boilers improved while using the shingle materials. Ash quality remained acceptable, and no issues with residues or fouling were noted while using properly sized material.

A full report of the testing and a summary of the test results are included in Appendix C.

2. Issues

The physical configuration of the equipment and the design of the boiler system did not allow for rigorous control of the various factors affecting emissions and operations, and operational problems unrelated to feeding the shingle materials limited the amount of useful data that could be collected during the trial.

A portion of the shingle materials contained oversize pieces up to 8 inches. These oversize pieces caused instability in the fluidized bed and resulted in an unacceptable residue in the boiler. No problems were noted with properly sized materials (less than about 1 inch).

The feeding mechanism for the shingle materials did not allow a consistent, well controlled feed rate. Therefore, the feed rates of up to 40% of the fuel by weight were approximate values, and it is expected that a more uniform feed would result in greater improvements in emissions and operational stability.

Although there was some clumping of the shingle materials in the stockpile, the clumps were easily broken. Where a partially closed knife gate obstructed the flow from a feed hopper, air lances were required to maintain flow, but the materials otherwise flowed well through hoppers, screw conveyors and drag conveyors.

The boilers used in this trial were very small and unique in design. During the testing, it became apparent that changes in relative humidity had an effect on emissions. The mechanism causing this effect is not clearly understood and is under further investigation. Changes in relative humidity during the testing made comparisons of emissions data difficult, but it appears that SO_2 and NO_x were consistently reduced using the shingle materials.

There was no opportunity during this testing to determine whether the shingle materials could be used to reduce limestone consumption in the boilers.

3. Technical Feasibility

The use of shingle materials in CFB boilers appears technically feasible based on this trial. The shingle materials performed well in the fluidized bed, and no issues related to residues or fouling were noted. In the small boilers used for this trial, stability of the operation was increased while emissions of SO_2 and NO_x were reduced. This increase in stability while improving emissions was the greatest benefit for these boilers. The potential also exists to reduce limestone consumption.

It appears that the increase in stability and the reduction in emissions were due to the slower burning nature of the shingle materials compared to the coal wastes being used as the primary fuel in these boilers. The slower combustion resulted in longer retention times and lower bed temperatures leading to lower emissions.

Many factors influence the performance of a CFB boiler, including the size of the combustion chamber, the design of air flows and the configuration of the circulation system. The maximum proportion of shingle materials that could be used in a given system would have to be determined on a case-by-case basis.

Longer term testing would be required to evaluate the impact of shingle materials on boiler efficiency. Abrasion of the boiler internal surfaces by the shingle granules should also be evaluated.

The results of this trial suggest that shingle materials including the granules may produce more improvement in SO_2 emissions than the materials without granules, probably due to the higher percentage of mineral content. This suggests that reductions in limestone consumption would be possible. Further testing would be required to confirm this possibility.

E. Use in Shingle Manufacturing

Potential exists to use portions of chipped roofing tear-off wastes in the manufacture of new asphalt shingles. After the tear-off wastes are chipped, separating the materials by sieving produces material groups having characteristics amenable to particular uses. The coarser fraction above the #12 mesh size contains a higher percentage of organic materials, and is particularly suitable for use as fuel or in HMA applications. As described below, the remaining materials below the #12 mesh size were studied to determine their potential for use in manufacturing new shingles.

1. Substitute Headlap Granules

a) Summary

The chipped tear-off materials in the -12/+20 mesh range have potential for use as headlap granules. Headlap is that portion of each shingle that will be covered by the succeeding course of shingles when installed (see Figure 2). While prime granules on the portion of each shingle that will be exposed when installed must meet exacting standards for color, granules on the headlap portion of the shingle do not, since they are not visible after the shingles have been installed. Prime granules must meet rigid criteria for adding performance value to the customer, while the headlap granules have little impact on customer value. Thus, a wider range of materials can be used for headlap granules.

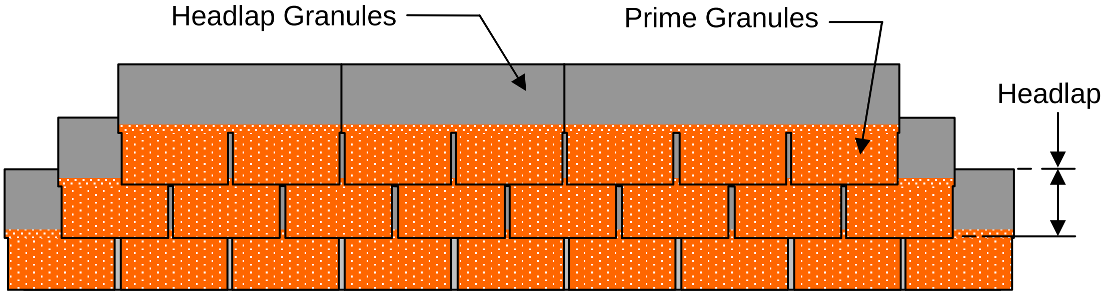


Diagram of Installed Shingles
Showing Headlap Area
Figure 2

Pilot scale testing was done using recycled materials blended with standard headlap granules in a ratio of 15% recycled to 85% standard. Shinglets made with these materials were tested, and a full scale trial at a shingle manufacturing plant was recommended. A report of the pilot test is included in Appendix D.

A full scale trial using the 15% to 85% recycled material to standard granules blend was conducted and shingles produced were evaluated according to standard quality control criteria. A report of the truckload trial is included in Appendix E.

b) Issues

The use of recycled tear-off materials to recover granules requires blending the recycled granules with standard raw granules to facilitate material handling and flow. Otherwise, re-agglomeration of the chipped materials occurs, and the materials do not flow through hoppers and feed equipment. This requirement results in additional costs for blending and transporting granules.

c) Technical Feasibility

Due to the fresh asphalt content of shingle manufacturing scrap, separation of the granules by sieving was not feasible. Sticking and agglomeration prevented effective sieving. With the more oxidized asphalt content of roofing tear-off wastes, effective separation by sieving was possible.

The use of the -12/+20 mesh fraction of chipped tear-off wastes as a substitute for headlap granules is technically feasible based on the pilot testing and full scale trial. Shingles produced with a blend of 15% recycled and 85% normal headlap granules met the quality criteria for new shingles, and no deterioration of shingle properties was noted.

As stated above, blending of recycled materials with standard headlap granules is required to maintain flowability. Lightweight fibers in the recycled materials caused some problems with blinding of screens in the handling equipment, and removal of this fraction by air separation is recommended.

Field evaluation of shingles produced with recycled headlap granules should also be conducted to insure that problems with sticking, scuffing or rust do not occur. While laboratory testing showed no problem with algae, testing to evaluate whether recycled materials containing algae would have a detrimental effect on algae resistance is also recommended.

2. Substitute For Filler and Asphalt

a) Summary

The chipped tear-off materials finer than 20 mesh have a physical and chemical composition amenable to use as a substitute for limestone filler and asphalt. Laboratory testing was conducted to confirm the compatibility of the materials, and a pilot scale trial was conducted to evaluate the mechanical and weathering properties of shinglets made with the recycled materials.

A report of this testing is included as Appendix F.

b) Issues

Aside from insuring that shingles made with recycled tear-off materials meet applicable quality control criteria, material handling and processing issues are of concern. Since the recycled materials contain asphalt, handling and processing these materials, particularly in high temperatures can become problematic (e.g. agglomeration). In addition, fibers in the chipped wastes have the potential to cause clogging problems in the process equipment (e.g. filtering screens, etc.) if not adequately separated prior to use.

Due to the limitations with handling filler containing asphalt in the existing manufacturing facilities, full scale testing of the use as a filler and asphalt substitute was not possible without significant capital expenditures.

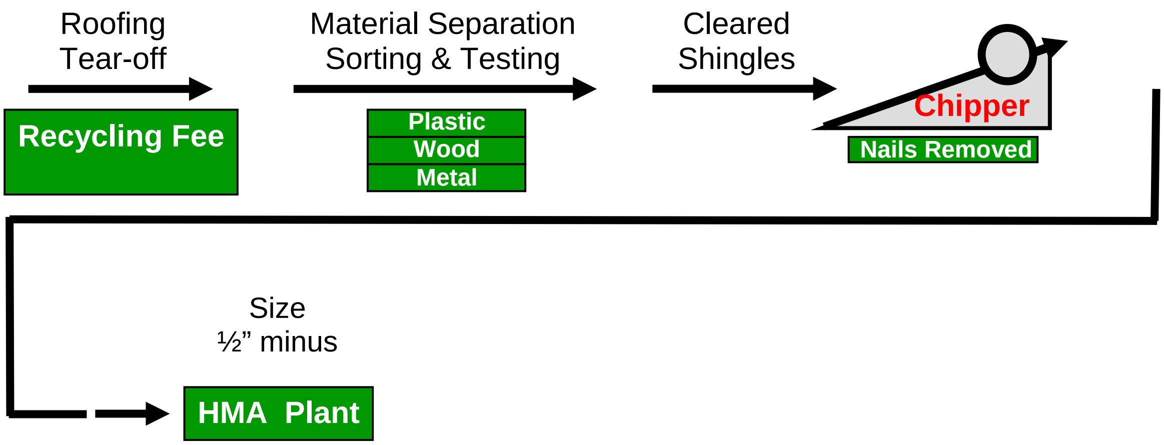
c) Technical Feasibility

As stated above in the headlap discussion, the separation of materials by sieving of shingle manufacturing scrap is not feasible due to problems with sticking and agglomeration. The use of the -20 mesh fraction of chipped tear-off wastes as a substitute for limestone filler and asphalt shows promise, based on the pilot testing done. However, blending of the recycled material with standard filler material is necessary to maintain flowability of the material. Once the material is blended, existing equipment at the manufacturing plants cannot handle the blended material due to the asphalt content. Therefore, additional equipment and processing systems would have to be designed and implemented before full scale testing could be conducted.

V. Economic Feasibility

A. General

The uses of residential roofing tear-off wastes in hot mix asphalt, cement manufacturing, CFB boilers and in shingle manufacturing all require chipping of the materials to a size appropriate for the application. Figure 3 shows a schematic of the steps necessary for processing roofing tear-off wastes. For manufacturing wastes, the material separation, sorting and testing step would not be required due to the homogeneous nature of the stream.



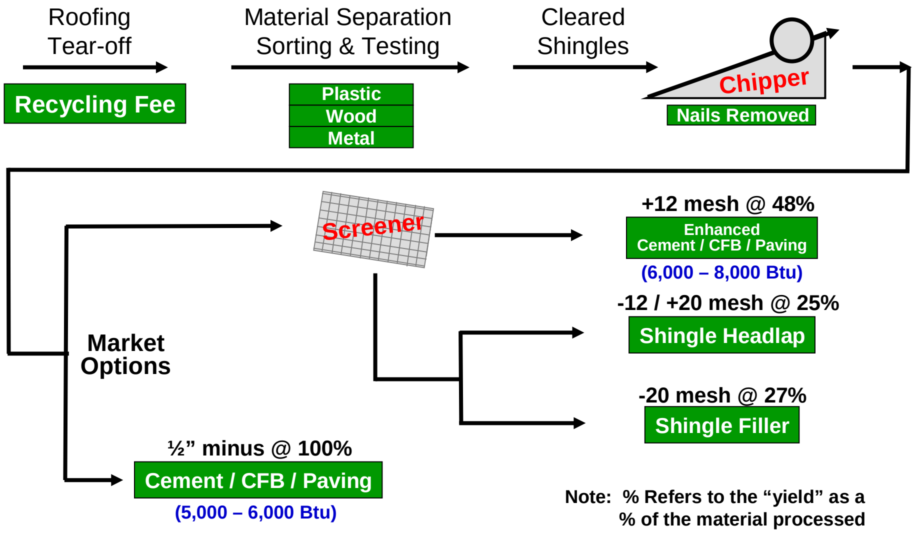
Shingle Recycling Operation
Figure 3

Roofing tear-off materials are placed into roll-off boxes or trailers for transport to either a landfill or recycling center. Methods of separating roofing materials to be recycled from other debris vary, with some recyclers requiring source separation and others accepting mixed loads. Loads arriving at the recycling center should be tested for the presence of asbestos before further handling. Loads found to contain asbestos must be handled and disposed of in accordance with applicable federal, state and local regulations to protect human health and the environment.

Once materials have been determined to be free of asbestos, they may be further sorted to remove non-recyclable debris and sent to a stockpile for chipping.

As the materials pass through the chipping equipment, nails are removed, and the chipped materials are sent through a screen to insure proper sizing.

In order to develop markets in addition to the HMA market for recycled asphalt shingles, a method of enhancing the value for certain applications by separating chipped materials by size fraction was explored. In this method, chipped materials are further sieved to recover the fractions of interest to particular markets as shown in Figure 4.



Enhanced Material Separation
Figure 4

This project demonstrated that the fuel value of chipped shingle materials can be enhanced by varying the sieve size for the material. See Appendix G for the results of a heat content study performed as a part of this project. Materials remaining after optimizing the heat value of materials prepared for use as fuel have potential for use in new shingle manufacturing as discussed previously.

Transportation cost is a key component of using shingle wastes in the applications investigated in this study. Therefore, the markets for chipped shingle materials will be local, say within 30 to 50 miles of the recycling center. The best case scenario would be one in which the recycling center is in close proximity to potential markets and at least as close to the rooftops as available landfills are.

B. Cost Information

Based on the experience gained during this project, the following costs for each step of the recycling process were estimated by the recycling contractor:

1.	Tipping Fee Received	($20 / ton) delivered to recycle center
2.	Staging & Testing	$5 / ton of tear-off material
3.	Chipping	$13 / ton of tear-off material
4.	Sieving	$8 / ton of tear-off material
5.	Blending	$5 / ton of blended material
6.	Storage & Loading	$1.50 per ton of material loaded

C. Business Case

1. General

The recycling center operators are probably in the best position to develop markets for the waste materials. For the purposes of this analysis, it is assumed that the recyclers' incentive is based only on potential tipping fees for incoming loads and potential sales of the chipped materials to the various markets within 30 to 50 miles. It is also assumed that backhauls are not available to reduce transportation costs.

The scale of a recycling operation would affect the cost structure. Since the markets are likely to be limited to a local area due to transportation costs, larger scale operations may not realize the economies of scale that one might expect. Based on the facilities currently being used for processing shingle materials for recycling, it is reasonable to assume a recycle center can process 100 tons of shingle materials per day.

Based on the trials conducted for this study, a recycling center processing 100 tons per day could be expected to produce the following materials, depending on the screening and sieving configuration.

Size	**-3/8”**	**-3/8 / +12**	**-12 / +20 (granules)**	**-20**
Suitable For	HMA, Fuel	HMA, Fuel	Headlap	HMA, Fuel, Shingle Filler
Normal	100 tons (100%)			
Granules Separated		48 tons (48%)	25 tons (25%)	27 tons (27%)

Note: In accordance with the industry practice, particle sizes larger than ¼ inch are designated by the size corresponding to the opening in the sieve screen, while smaller sizes are designated by a mesh size corresponding to the number of openings per linear inch in the sieve.

Table 2

2. Hot Mix Asphalt (HMA)

Virgin asphalt used for producing HMA varies along with the oils from which they are produced. The cost for virgin asphalt ranges from $350 per ton to well over $400 per ton in some areas, making asphalt the most expensive material component of HMA. As costs continue to rise, recycled asphalt shingle materials are increasingly being recognized as a valuable source of asphalt.

An average size HMA plant produces from 195,000 to 250,000 tons of HMA per year. Table 3 shows the savings that could be realized by a 200,000 ton plant using 5% shingle materials. Note that the use of 5% shingle materials in HMA allows for a decrease in the virgin asphalt content of about 20% from 5% virgin asphalt to 4% virgin asphalt.

As shown in the table, the theoretical value of the shingle materials would be about $70.00 per ton, so long as freight costs for asphalt and shingles are equivalent. Given the additional handling and storage requirements at the HMA plant site and the market conditions that exist, prices in the range of $15 to $25 per ton of shingles are common.

	HMA w/o Shingles	**HMA w/ 5% Shingles**
Tons HMA Produced	200,000 tons	200,000 tons
Virgin Asphalt Used	10,000 tons @ 5%	8,000 tons @ 4%
Cost of Virgin Asphalt @ $350 per ton	$3.5 MM	$2.8 MM
Annual Savings		$700,000
Shingles Used @ 5%		10,000 tons
Savings per Ton of HMA		$3.50 per ton of HMA
Value of Shingles		$70.00 per ton of shingles

Estimated Theoretical Value of Shingles in HMA
Table 3

Table 4 shows the processing costs for shingle materials suitable for use in HMA production. Note that with a market price in the range of $15 to $25 per ton, the tipping fee available and the transportation costs will determine feasibility.

Item	**Normal Material Rate $ per ton**	**Enhanced Mat'l Rate $ per ton**
Sorting & Testing	$5.00	$5.00
Chipping	$13.00	$13.00
Sieving & Separating	n/a	$8.00
Sub-Total Direct Processing Cost	**$18.00**	**$26.00**
O'head & Profit @ 15%	$2.70	$3.90
Total Processing Cost	**$20.70**	**$29.90**
Less Shingle Tipping Fee	($20.00)	($20.00)
Net Processing Cost	**$0.70 / ton**	**$9.90 / ton**

Note: Values shown for tear-off wastes. Use of manufacturing scrap would eliminate sorting & testing costs. Enhanced material refers to tear-off wastes only.

Processing Cost For Materials Suitable for HMA
Table 4

3. Cement Manufacturing

Cement kilns typically burn coal as their primary fuel. At prices of around $60 per ton of coal, energy cost would be about $2.30 per million BTU. At about 6,000 BTUs per pound, shingles would have a theoretical fuel value of about $27.60 per ton less the difference in freight between coal (typically shipped by rail) and shingles (shipped by truck). Given the other fuel options available and the challenges associated with permitting fuels for cement kilns, an actual price of $12.00 per ton (about $1.00 per MMBTU) delivered to the cement plant was negotiated.

However, cement kiln operators expect significant savings or remuneration for the additional problems and costs associated with handling, storing, measuring and controlling an additional feed stream to the kiln. In addition, obtaining permits for various fuels is expensive and time consuming, and more attractive alternatives are available. Based on discussions with cement manufacturers, it is unlikely that a cement plant would pay any amount beyond the freight costs for shingle materials.

4. CFB Boilers

CFB boilers burning waste coal (coal from waste piles containing impurities, low heat value, poorly sized, etc.) pay between $1 and $1.50 per million BTU. Again based on 6,000 BTUs per pound, shingles would have a theoretical value of about $15 per ton, less any difference in freight. Limestone costs are very dependent on freight costs, but costs in the range of $20 to $25 per ton of limestone have been reported. However, while potential for savings from limestone reduction is possible, it could not be definitively evaluated in this study.

Table 5 shows the processing costs associated with the materials suitable for use in CFB boilers. Based on discussions with CFB boiler operators and fuel suppliers, it is estimated that the maximum market price for shingle materials would be about $15 per ton delivered to the boiler. Since this is near the theoretical value as fuel, transportation costs will limit the use of shingle materials in CFB boilers to locations very close to the processing facility.

Item	**Normal Material Rate $ per ton**	**Enhanced Mat'l Rate $ per ton**
Sorting & Testing	$5.00	$5.00
Chipping	$13.00	$13.00
Sieving & Separating	n/a	$8.00
Sub-Total Direct Processing Cost	**$18.00**	**$26.00**
O'head & Profit @ 15%	$2.70	$3.90
Total Processing Cost	**$20.70**	**$29.90**
Less Shingle Tipping Fee	($20.00)	($20.00)
Net Processing Cost	**$0.70 / ton**	**$9.90 / ton**

Note: Values shown for tear-off wastes. Use of manufacturing scrap would eliminate sorting & testing costs. Enhanced material refers to tear-off wastes only.

Processing Costs For Material Suitable For CFB Boilers
Table 5

5. Shingle Manufacturing

As stated in a previous section, use of fine material from chipped shingle wastes as a substitute for filler and asphalt in the production of new asphalt shingles requires significant capital investment before trials could be conducted. Therefore, this application is not considered as a viable use at this time.

Table 6 shows the analysis of obtaining granules from chipped shingle materials for use as headlap. As stated in the section on technical feasibility, recycled granules must be blended with standard headlap granules to avoid re-agglomeration and insure flowability. Based on the trials conducted as part of this study, a ratio of 85% standard granules to 15% recycled granules is required. Thus, for every ton of recycled granules, 6.67 tons of blended granules would be handled. Note then that for every ton of recycled granules, 6.67 tons of blended granules would have to be hauled from the recycle center to the shingle manufacturing facility.

Material	Tons	Rate $ per ton of Mat'l Processed To Recover 1 ton of Granules	Cost Per Ton of Granules Recovered
Shingles Processed	4		
Granules Recovered	1		
Sorting & Testing	4	$5.00	$20.00
Chipping	4	$13.00	$52.00
Sieving	4	$8.00	$32.00
Standard Granules Required @ 85%	5.67		
Recovered Granules @ 15%	1.0		
Blended Granules	6.67	$5	$33.35
Direct Processing Cost			$137.35
O'head & Profit @ 15%			$20.60
Total Processing Cost			$157.95
Less Shingle Tipping Fee	4	($20.00)	($80.00)
Less Sales to Fuel Use	3	($5.00)*	($15.00)
Net Processing Cost			**$62.95 / ton**

Note: Assumes sale price of $5 per ton in excess of transportation costs for "enhanced" material for use as fuel.

Processing Costs For Recycled Granules For Headlap
Table 6

6. Business Case Summary

As shown in the sections above, transportation costs require that end use applications for chipped shingle materials be in close proximity to the recycle center. Use in HMA shows the most promise with the potential to replace a portion of increasingly expensive virgin asphalt.

Use in cement kilns is technically feasible, but most kilns will not pay a significant amount for the materials. CFB boilers are also well suited technically. Since the boilers can more easily handle the shingle materials, pricing could be attractive. However, transportation costs will render most projects infeasible.

Likewise, transportation costs make the use as replacement for headlap granules unattractive, unless the recycling center is very close to the shingle plant.

VI. Conclusions & Recommendations

A. General

This project study found that while the uses of chipped asphalt shingle materials in hot mix asphalt, as fuel in cement kilns and CFB boilers and as a source of raw materials for manufacturing new shingles are technically feasible, testing and processing costs added to transportation costs prevent further development of the markets. Most all concerns about asbestos in roofing tear-off wastes can be addressed through education, training and procedures for testing and handling.

The study demonstrated that the characteristics of chipped residential roofing tear-off wastes and chipped waste from asphalt shingle manufacturing are compatible with end uses in hot mix asphalt, as fuel for cement kilns or CFB boilers and as replacement for a portion of headlap granules in shingle manufacturing.

Use in hot mix asphalt is the most promising application, since the asphalt content of the shingles can replace a portion of increasingly expensive virgin asphalt. The body of experience using shingles in HMA is well established and growing, and a local infrastructure of contractors, haulers, processors, pavers, etc. has been established.

All of the uses studied in this project require the roofing materials to be chipped. While use as fuel may be viable at a top size of about one inch, most applications benefit from a smaller top size of about $^3/_8$ inch.

Financial incentives may be necessary to overcome the barriers to developing the uses studied in this project. Reuse and recycling of asphalt shingle materials would benefit the environment in terms of reducing land disposal, greenhouse gases and toxic emissions. Beneficial reuse of these materials would also benefit the economy as roofing contractors would have cost effective options for disposal, and haulers, processors and others involved in the recycling process would have opportunities to expand or enter the market.

Education of contractors, recyclers, environmental regulators, departments of transportation and potential end users of recycled shingle materials may be helpful to further develop the markets.

B. Asbestos

While the presence of asbestos in residential roofing tear-off wastes is infrequent, it will continue to be of concern for the near future. As the number of older roofs containing asbestos declines, the occurrence of asbestos in the tear-off wastes will also decline.

This project reviewed field practices and found that asbestos containing materials can be readily identified with proper training of the contractor personnel. Laboratory testing of materials can be used to insure that materials are asbestos free, however the delay in obtaining test results requires that large amounts of storage area be available for materials that are being held pending test results. Some recyclers have on-site laboratory facilities in order to reduce turnaround time.

Results of limited testing showed that asbestos was found to be present in 1.67% of the loads arriving at the processing center, consistent with findings from other studies.

Air sampling near the shingle processing equipment showed that respirable fibers are well below standards protective of workers.

This project also demonstrated that asbestos can be effectively destroyed in cement kilns. Under cement kiln conditions, the asbestos fibers undergo an irreversible transformation into a different, benign crystalline phase.

C. Hot Mix Asphalt

As stated above, use of chipped shingle materials in HMA is the most attractive application at this time. This market can be expanded by sharing information on the performance record of pavements made with HMA containing recycled shingle materials and educating department of transportation personnel and contractors regarding the benefits.

D. Cement Manufacturing

Greater incentives are required to interest cement manufacturers in the use of shingle materials in cement kilns. Education of regulators and the public regarding the environmental benefits of using these materials could help reduce the permitting difficulties for cement companies. Full scale trials to show the benefits and confirm the emissions effects are recommended, but more attractive business opportunities exist for cement manufacturers interested in alternative fuels.

E. CFB Boilers

CFB boilers can benefit from the use of shingle materials, and further testing is recommended to evaluate the effects on boiler efficiency and to determine whether reductions in limestone consumption could be achieved. As above, education of the public and of the regulatory agencies may be helpful in reducing permitting hurdles.

The use of shingle materials in CFB boilers is an area for possible development, but is currently limited to situations in which transportation costs are quite low.

F. Shingle Manufacturing

The granules recovered from roofing tear-offs can be used as substitute raw materials, but the requirement to transport a large quantity of standard granules for blending reduces the economic feasibility of this application. Further investigation into methods of handling recycled granules is necessary. This application is not currently economical.

VII. Appendices

A. ***Technical Feasibility Report – Use of Asphalt Roofing Materials In Cement Manufacturing – Pilot Test of Shingle Waste In A Precalciner,*** *Bayside Business Development, LLC., Oregon, OH*

B. ***The Fate of Asphalt Shingles Containing <1% Asbestos in Cement Kilns,*** *Environmental Studies International, New York, NY*

C. ***Technical Feasibility Report – Use of Asphalt Roofing Materials In CFB Boilers – Pilot Test of Shingle Tear-Off Waste In A Small Commercial CFB Boiler,*** *Bayside Business Development, LLC., Oregon, OH*

D. ***Recycled Shingle as Headlap Material Substitute in Roofing Shingles,*** *Owens Corning Science & Technology Center*

E. ***Recycled Shingle as Headlap Material Substitute in Roofing Shingles: Truckload Trial,*** *Owens Corning Science & Technology Center*

F. ***Recycled Shingle as Filler and Asphalt Substitute in Roofing Shingles,*** *Owens Corning Science & Technology Center*

G. ***Slides showing results from the study of heat content in asphalt shingle materials*** *by Owens Corning Science & Technology Center*

H. ***Other Useful Information***

   Enhanced Recovery of Roofing Materials*, Prepared for Canadian Construction Innovation Council by Athena Sustainable Materials Institute, January, 2007*

Appendix A

Technical Feasibility Report
Use of Asphalt Roofing Materials
In Cement Manufacturing

Technical Feasibility Report
Use Of Asphalt Roofing Materials In Cement Manufacturing

Pilot Test of Shingle Waste In A Precalciner

Conducted By FL Smidth
At The FFE Minerals Facility
March 19, 2007 – March 23, 2007
For Owens Corning & Cemex

Report prepared for Owens Corning by Rex Jameson, P.E.
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Executive Summary

As part of Owens Corning's commitment to sustainable development, this premier manufacturer of asphalt roofing shingles in the United States is investigating beneficial uses for waste shingle materials, both manufacturing wastes and wastes arising from tear-off of shingles as roofs are replaced.

One possible use for both of the shingle materials is as a fuel and raw material replacement in cement kilns. Portland cement is manufactured by processing limestone, silica, alumina, iron and other trace elements at extremely high temperatures to the point of fusion in rotating kilns. At these high temperatures, the proper minerals are formed to give cement its hydrating properties. The minerals are formed into a nodule called a clinker by the tumbling action in the kiln. The resulting clinker is finely ground with other additives to form the grey powder called Portland cement.

Achieving the high temperatures necessary to form clinker requires at over two million BTUs per ton (2,326 kj/kg) of clinker produced, depending on the equipment and materials being used. Coal is the primary fuel being used in cement manufacturing, and the industry is seeking alternatives to achieve lower costs and fewer emissions.

In order to determine the effects of feeding waste shingle materials into the preheater unit of a cement kiln system, a feasibility pilot scale test was conducted at FL Smidth's FFE Minerals facility near Bethlehem, Pennsylvania. Using raw feed materials from Cemex's Fairborn, Ohio cement plant, four test conditions were evaluated: 1) baseline with no shingle addition, 2) addition of shingle tear off materials (TO), 3) addition of materials from manufacturing scrap (MW), and 4) addition of shingle tear off materials screened to remove most of the granules (TO+12). All roofing materials were prepared in advance by removal of deleterious materials and chipping to an appropriate size.

Materials were fed into a flash calciner vessel heated by natural gas and fuel oil as shown in Figure 1. During each test condition, emissions were monitored from the stack downstream of the baghouse filter. Calciner product was collected in drums as were the fines collected by the baghouse filter. The calciner product, representative of material that would enter a kiln from the preheater, was analyzed to determine probable effects on clinker quality.

Some clogging occurred due to the dropout of shingle granules at the base of the calciner. In a full scale preheater or precalciner, dropout could probably be minimized or avoided by careful placement of the introduction point, and the effects of dropout on kiln operations could be mitigated by proper placement as well. However, full scale testing would be required to address this issue.

No emissions results were problematic from a compliance standpoint, with all results well below levels of concern. However, results for certain pollutants varied unexplainably. It appears that most of these variances were not related to the shingle material feed as described in this report.

Results of the pilot scale test show that use of these materials in cement manufacturing is technically feasible. The test showed minimal effect on clinker quality parameters and emissions. Full scale testing in a cement manufacturing facility is warranted to demonstrate adequate control of chemical variations, to determine proper placement of the introduction point and to evaluate the impact on NO_x emissions. No barriers to full scale testing were discovered.

DIAGRAM OF PILOT SCALE FLASH CALCINER SYSTEM

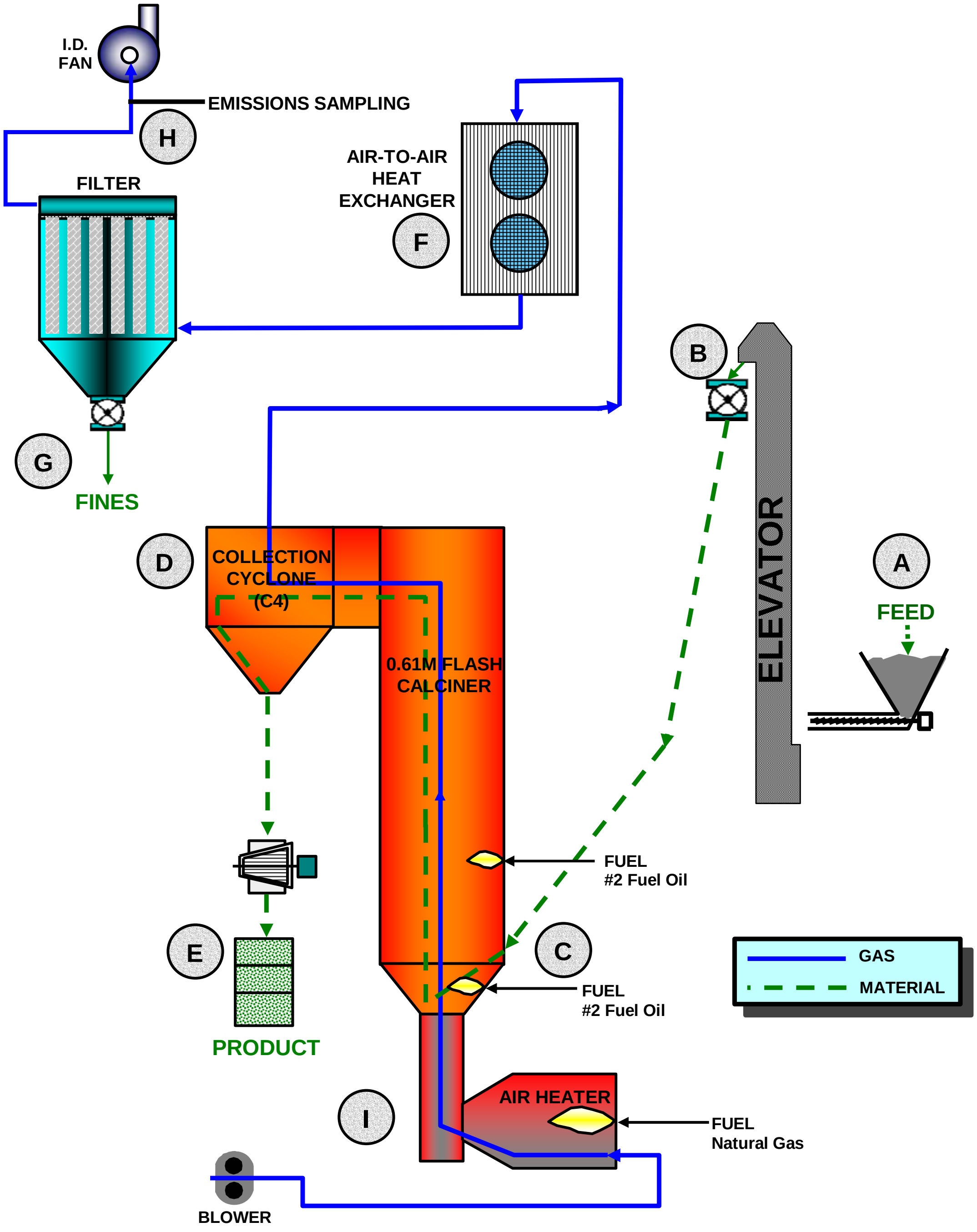


Figure 1

I) Introduction

Asphalt roofing shingles have been used in the United States for residential and commercial sloped roof applications for many years. While some scrap is generated during the manufacturing process, waste is also generated when aging roofs are torn off and replaced. There are several beneficial uses for manufacturing waste, including reuse in shingle manufacturing and use in hot mix asphalt production. Roof tear off wastes are typically landfilled as construction and demolition debris.

In an effort to develop more beneficial uses for the entire life cycle of asphalt shingles, Owens Corning is investigating the use of these materials in the manufacture of Portland cement.

Portland cement is produced by heating materials containing calcium, silica, alumina and iron to the point of fusion in a rotating kiln. The calcium is typically obtained from limestone or marl, and the other components are obtained from clay, fly ash, sand and a variety of other materials.

At the high temperatures in the kiln, the materials become molten, forming new minerals with hydrating properties. As the new minerals tumble in the kiln nodules called clinker are formed. Once the clinker leaves the kiln and is cooled, it is finely ground with other additives to form the grey powder called cement. This cement is mixed with sand, stone and water to form concrete for use in buildings, roads and other structures.

In a modern cement manufacturing facility, the cement making raw materials are fed into the top of a stationary preheater tower, through a series of counter-current cyclones, and into the rotating kiln. In some cases, the materials also pass through a precalciner chamber where heat is added to begin driving the carbonates from the materials just prior to entering the rotating kiln.

Cement making materials must be heated to about 2750 °F (1,510 °C) to form clinker. Pulverized coal is the predominant fuel used in the production of cement, and ash from the coal is incorporated into the clinker. Even in an efficient preheater/precalciner kiln system, the proper formation of clinker minerals requires about 2.5 million BTUs per ton (2,908 kj/kg) of clinker produced. Since energy costs amount to about one third of the total cost of producing cement, the industry is searching for alternative fuels that would reduce these costs.

The cement manufacturing process is regulated under the Clean Air Act, and facilities must meet standards for emissions of particulate matter (PM), total hydrocarbons (THC) and dioxins and furans (D/F). Operating permits typically also require control of NO_x and SO_x emissions.

A modern asphalt roofing shingle consists of a fiberglass mat, asphalt coating, granules, limestone dust and additives. These materials are compatible with the cement manufacturing process, and could be utilized as a source of fuel (from the asphalt) and raw materials (from the granules, fiberglass mat and limestone dust) for clinker production.

In order to demonstrate the technical feasibility of utilizing shingle materials in the production of cement clinker, a partial pilot scale test was conducted. This report addresses the technical results of the test, but does not address financial aspects.

II) Description of the Pilot Scale Test

A) General Description

In a typical cement manufacturing facility, the appropriate point for introduction of supplemental alternative fuels would be in the preheater tower or in the precalciner vessel. In order to demonstrate the feasibility of roofing shingles in such an application, a pilot test was conducted at FFE Minerals' facility near Bethlehem, PA. Materials were fed into a pilot scale flash calciner. The materials exiting the calciner were evaluated for potential effects on clinker quality, and emissions of selected metals, dioxins/furans, NO_x, SO_x, THC and CO were monitored. No attempt to actually form clinker in a pilot kiln was made, since the scale of the test and configuration of the equipment would not have yielded meaningful data.

Cement making raw materials (raw meal) from Cemex's Fairborn, OH cement plant were used for the test. Shingle materials were obtained from a processing facility which removed deleterious materials such as large pieces of wood or metal and chipped the materials to an appropriate size. Four conditions were evaluated as follows:

1. Baseline feeding only Cemex raw meal,
2. Addition of chipped roofing tear off waste (TO),
3. Addition of chipped shingle manufacturing waste (MW),
4. Addition of chipped roofing tear off waste, screened to remove most of the granules (TO+12).

Test Condition	Raw Meal	Raw Meal Rate lbs/hr	Shingle Material	Shingle Feed Rate lbs/hr
1	Cemex Fairborn	370	None	0
2	Cemex Fairborn	372	TO	22
3	Cemex Fairborn	372	MW	22
4	Cemex Fairborn	372	TO+12	13

Table 1

Raw meal was fed to the system from bulk bags (FIBCs) into a hopper feeding a screw conveyor (point A in Figure 1). Shingle materials were fed into a separate hopper, through a second screw conveyor. Raw meal and shingle materials came together in the feed chute of a bucket elevator, which transported the combined feed to a rotary feeder (point B in Figure 1). The rotary feeder metered the materials into a chute which dropped into the base of the flash calciner (point C in Figure 1).

Once the feed materials entered the base of the flash calciner, they were swept upward by the flow of preheated air, through the calciner vessel and into a cyclone separator (point D in Figure 1). The material dropping out of the cyclone represented the calciner product (point E in Figure 1), while the fine fraction was carried by the gas flow to a baghouse filter. An air to air heat exchanger was located prior to the baghouse to prevent excessive baghouse temperatures

Air to the flash calciner was heated with a natural gas burner. Burners at two locations in the flash calciner vessel were fired with #2 fuel oil.

B) Testing

Cemex's Fairborn, OH plant has a preheater kiln system with no precalciner. In order to evaluate the effects on materials entering the kiln from such a system, temperatures in the pilot unit were adjusted to maintain a loss on ignition (LOI) for the calciner product of 16% to 18%.

The feed rate of materials was monitored by weighing timed samples on a periodic basis. Process parameters were recorded hourly and samples of calciner product and baghouse fines were taken hourly as well.

Gaseous emissions were monitored downstream of the baghouse filter, upstream of the ID fan as shown on Figure 1, point H.

Several representative raw meal samples were taken from the materials delivered from Cemex, and a composite sample was tested for use in the analysis. Grab samples of shingle materials were taken from each type of material evaluated. Samples of calciner product and baghouse fines were taken hourly during each test condition, and composite samples of each material were prepared for each test condition.

For each material stream (raw feed, shingles, product and baghouse fines), metals analyses were performed. The metals tested and the rationale for testing each are shown in Table 2.

Metal Tested	**Rationale**
Beryllium	Carcinogenic metal with tendency to partition to product.
Cadmium	Semi-volatile metal with tendency to partition to baghouse fines & gaseous emissions.
Chromium	Carcinogenic metal with tendency to partition to product. Also metal of concern for cement manufacturing related to cement worker safety.
Hexavalent Chromium	Most toxic form of chromium.
Copper	Copper is used as an algae inhibitor in shingle manufacturing. Copper is also thought to be a catalyst for dioxin/furan formation.
Mercury	Volatile metal with a tendency to be emitted in gaseous form and a target for future regulation.
Nickel	Carcinogenic metal of concern to various state agencies.
Lead	Semi-volatile metal with a tendency to partition to baghouse fines & gaseous emissions.
Zinc	Metal of concern for cement manufacturing due to adverse effect on cement set times.

Table 2

Gaseous emissions were monitored during each condition evaluated. Three test runs were conducted at each condition. Testing was performed for dioxin/furans (D/F), SO_x, NO_x, total hydrocarbons (THC), CO and the metals listed above.

Table 3 shows the comparison of metals concentrations in mg/kg (ppm) among the raw meal and the three shingle materials evaluated. The "<" symbol indicates that the element was not detected at the level shown. Except for the shaded values, the concentration of metals in shingle material was either lower than in raw meal or not significantly different from raw meal.

Metal	Raw Meal	TO	MW	TO+12
Be	< 0.854	< 0.834	< 0.899	< 0.842
Cd	< 0.854	< 0.834	< 0.899	< 0.842
Cr	10.6	16.8	< 8.99	24.0
Cr+6	0.11	< 0.05	0.056	< 0.05
Cu	14.8	15.4	46.1	18.6
Hg	0.348	< 0.194	< 0.191	0.336
Ni	8.95	14.2	9.41	15.7
Pb	9.22	39.9	< 8.99	41.1
Zn	22.3	69.9	22.6	115

Table 3

C) Timeline

The pilot unit was started early in the morning on March 19, 2007. During most of that day, the unit was calibrated and adjusted to achieve the target LOI on the calciner product. During that evening, baseline data was gathered feeding raw meal only. Two test runs were completed, and feed was stopped until the next morning.

On the morning of March 20, the third test run for the baseline condition was completed. Shortly after noon, shingle tear off (TO) material was fed, and three test runs were completed through the afternoon and into the night.

On the morning of March 21, the feed of shingle manufacturing waste (MW) was started. Granular material built up in the throat of the calciner (point I in Figure 1), forcing a temporary shut down of the unit, but the three test runs were completed after cleaning of the throat.

In the early morning hours of March 22, the feed of tear off materials screened to remove most of the granules (TO+12) was started. The air-to-air heat exchanger plugged that morning, requiring a shut down to clean it. The plugging was unrelated to the shingle and raw meal feed as discussed below. Other equipment malfunctions caused delays, but three test runs were completed by early morning on March 23.

III) <u>Challenges During the Testing</u>

A) General

One purpose of the testing was to demonstrate the feasibility of placing shingle materials into a preheater or a cement kiln system. The device used for this pilot demonstration was a flash calciner. Product from a flash calciner would typically have an LOI of less than 10%. Product from the exit of a preheater tower would typically have an LOI in the range of 16% to 18%. In order to simulate a preheater, the flash calciner was operated at a temperature below the normal range for the flash calciner.

The effect of this lower temperature operation was to increase the oxygen level at the calciner outlet. It was not practical to reduce oxygen to typical cement process levels while maintaining LOI in the range of 16% to 18%. The decision was made to maintain LOI rather than reduce oxygen. LOI values varied more than expected during the testing, but it does not appear that results are adversely affected.

During baseline testing, two sampling runs were completed on March 19. The calciner was idled for several hours after the first two runs due to the unavailability of the test crew. The third test run was completed on March 20. While it does not appear that the delay period affected test results, it inhibits the ability to determine the cause of a relatively large variation in CO levels among the three test runs conducted during that time.

The large variation in measured CO among the three baseline test runs causes the standard deviation of the baseline test to be relatively large, reducing the statistical significance of the testing that followed. Therefore, during the review of the data, tests for statistical significance were calculated using both actual data and "normalized" data with the outlying elevated CO measurement discarded. Use of the normalized data conservatively decreases the baseline CO level and increases the significance of observed changes during the subsequent test conditions. The conclusions reached from the testing are the same regardless of whether actual data or normalized data are used.

Two fuel oil burners located in the flash calciner vessel were utilized to control temperatures and LOI of the calciner product. The use of these burners introduced an additional set of process variables, making it difficult to isolate the cause of changes in emissions. For example, a change in emissions from one condition to another may be due to changes in the burner configuration being used rather than changes in feed materials.

B) Equipment Malfunctions

During testing, various equipment malfunctions caused interruptions in operations. Most notably, the air to air heat exchanger clogged with clay material from a previous test. Other interruptions occurred due to feeder failures. These interruptions may have contributed to variability in the testing results.

Also contributing to variability was the failure of the equipment to provide uniform feeding of materials to the unit. The feed hopper at the base of the elevator did not provide a uniform flow of material to the elevator. Materials would build up slightly in the hopper and slough off periodically. In addition, the screw feeder hoppers were prone to rat holing, which also contributed to an uneven flow of materials to the unit.

C) Data Collection

Feed rates were determined by the facility operators by weighing timed samples on a periodic basis. Feed rates were controlled by screw conveyors, which were held steady. However, it is unlikely that the timed sample weights were as consistent as shown on the operator data sheets.

While the weights of calciner product and baghouse fines were also recorded, flow rates cannot be accurately determined from these weights. This precludes the possibility of performing accurate mass balance calculations, which are important for determination of whether feed materials can account for observed changes in output streams (baghouse fines, calciner product and emissions).

IV) Effects on Calciner Product

A) Metals

For each condition evaluated, samples of calciner product were taken on an hourly basis. A composite sample was prepared for metals analysis. The results in mg/kg (ppm) are shown in Table 4. The "<" symbol indicates that the element was not detected at the level shown.

Metal/Condition	Baseline	TO	MW	TO+12
Be	< 0.978	< 0.962	< 0.978	< 0.964
Cd	< 0.978	1.23	< 0.978	< 0.964
Cr	14.6	16.7	15.0	16.0
Cr+6	1.5	1.5	3.5	4.5
Cu	17.3	19.3	26.0	21.3
Hg	< 0.191	< 0.185	< 0.189	< 0.183
Ni	9.86	11.5	10.2	11.5
Pb	10.9	35.7	10.9	16.0
Zn	23.2	40.5	< 19.6	28.7

Table 4

As shown, the addition of shingle materials has minimal impact on metals content of the calciner product. Shaded areas in the table indicate results that were investigated further in an attempt to determine the cause of the difference.

The apparent increase in Pb concentration for condition 2 (TO) was larger than anticipated and cannot be explained by the concentration of Pb in the shingle material. The Pb level for condition 2 is well below the average typically found in cement kiln dust (CKD) but higher than typically found in cement.

Likewise, the increased concentration of Zn in condition 2 is much larger than can be explained by the slightly higher Zn concentration in the shingle material. The level of Zn that can be tolerated by a particular kiln system is highly dependent on the chemistry of the raw meal, and the input of Zn to the process should be monitored.

The increase in Cr+6 concentration during conditions 3 (MW) and 4 (TO+12) are anomalous. Cr+6 concentration in the shingle materials is less than the concentration in the raw meal, and the operating temperature was not sufficient to convert trivalent chromium to the hexavalent form. Therefore, the apparent increase cannot be related to the feed materials.

B) Clinker Chemistry

The raw meal and each of the shingle materials used were analyzed for major oxides and loss on ignition, and the results were used to calculate the properties of the combined feed. The cement industry standard Bogue formulae were then used to calculate the theoretical resulting clinker composition.

It should be noted that clinker chemistry is highly dependent on the specific raw materials and fuels used at a particular plant. Therefore these results cannot be extrapolated or generalized but are valid for the materials used in the test configuration only.

As shown in Table 5, since the shingle materials were added to the raw meal stream and ash from coal was not a factor, the main impact of the shingle addition was to lower the lime saturation factor (LSF), decrease tricalcium silicate (C_3S in cement industry notation) and increase dicalcium silicate (C_2S in cement industry notation).

CHANGE IN CHEMISTRY & CLINKER COMPONENTS

Property	**TO (Condition 2)**	**MW (Condition 3)**	**TO+12 (Condition 4)**
SR	←→	↑ slight	↑ slight
A/F	↓	↑ slight	←→
LSF	↓	↓	↓
C_3S	↓	↓	↓
C_2S	↑	↑	↑
C_3A	↑ slight	↑ slight	↑ slight
C_4AF	↑ slight	Slight	slight

←→ = no significant change
↓ = decrease
↑ = increase

SR = Silica Ratio
A/F = Alumina – Iron Ratio
LSF = Lime Saturation Factor
$C_3S = 3CaO.SiO_2$
$C_2S = 2CaO.SiO_2$
$C_3A = 3CaO.Al_2O_3$
$C_4AF = 4CaO.Al_2O_3.Fe_2O_3$

Table 5

C) Burnability

Burnability refers to the relative ease with which a kiln feed material can produce the required clinker minerals. "Easy" burning materials require less heat to form clinker than "hard" burning materials. The burnability test consists of placing samples in a furnace at 2600 °F (1,427 °C) for ten minutes, 30 minutes and 60 minutes. The samples are then analyzed for various oxides of significance relative to burnability. A control sample was supplied by Cemex for free lime analysis to validate the test method.

In the pilot test, burnability testing was conducted on calciner product to determine the effect on materials entering the rotary kiln. Based on the oxide analysis, a relative burnability factor was calculated for each condition. While this factor cannot be used for comparison to typical values for raw feed, it is useful for comparison of each condition to the baseline condition. As shown in Table 6. use of the shingle materials did not have a significant impact on burnability of the calciner product.

Burnability Test Results
&
Relative Burnability Factor

	Baseline (Condition 1)			TO (Condition 2)			MW (Condition 3)			TO+12 (Condition 4)		
	10 Min	**30 Min**	**60 Min**	**10 Min**	**30 Min**	**60 Min**	**10 Min**	**30 Min**	**60 Min**	**10 Min**	**30 Min**	**60 Min**
SiO_2	19.90			20.70			20.1			20.4		
Al_2O_3	1.45			1.52			1.45			1.45		
Fe_2O_3	5.20			5.26			5.26			5.49		
CaO	65.60			63.00			63.1			64		
MgO	5.04			4.94			5.13			5.01		
K_2O	0.96	0.59	0.21	0.98	0.55	0.17	0.87	0.45	0.16	0.98	0.56	0.20
Na_2O	0.66	0.65	0.55	0.70	0.69	0.57	0.68	0.66	0.57	0.7	0.65	0.54
TiO_2	0.53			0.55			0.53			0.53		
MnO	0.08			0.08			0.07			0.08		
SO_3	0.47	0.33	0.19	0.40	0.26	0.14	0.43	0.28	0.15	0.58	0.40	0.18
Free CaO	7.31	4.27	2.59	3.90	1.72	0.80	7.21	4.31	2.93	6.38	4.03	2.69
LOI												
Total	99.89			98.13			97.62			99.22		

SR	2.99	3.05	3.00	2.94
A/F	0.28	0.29	0.28	0.26
LSF	1.08	1.00	1.03	1.02
Relative BF	**11.02**	**11.67**	**10.94**	**10.35**

SR = Silica Ratio
A/F = Alumina – Iron Ratio
LSF = Lime Saturation Factor
BF = Burnability Factor

Table 6

V) Effects on Baghouse Fines

For each condition evaluated, samples of baghouse fines were taken on an hourly basis. A composite sample was prepared for metals analysis. The results in mg/kg (ppm) are shown in Table 7. The "<" symbol indicates that the element was not detected at the level shown.

Metal/Condition	Baseline	TO	MW	TO+12
Be	< 0.979	< 0.997	< 0.988	< 0.987
Cd	< 0.979	< 0.997	< 0.988	< 0.987
Cr	30.0	27.9	37.7	31.0
Cr+6	0.32	< 0.2	< 0.1	0.25
Cu	24.3	23.8	23.2	27.7
Hg	2.74	2.50	1.02	1.92
Ni	19.4	18.5	18.2	17.8
Pb	26.8	32.1	24.0	53.0
Zn	335	327	142	434

Table 7

Minimal impact on metals concentrations in the baghouse fines was observed. Shaded areas in the table indicate results that were investigated further in an attempt to determine the cause of the difference.

The apparent increase in Pb concentration for condition 4 (TO+12) is larger than can be explained by the Pb concentration in the shingle materials based on an estimated mass balance. Likewise, the apparent decrease in Zn concentration for condition 3 (MW) and increase for condition 4 (TO+12) cannot be explained by the Zn concentrations in the shingle materials.

In order to determine whether the concentrations of Pb and Zn are cause for concern, the levels were compared to levels in cement kiln dust (CKD) and common soils as documented in EPA's Report to Congress concerning CKD. The concentration of Pb is well within the range normally found in CKD and in common soils. The level of Zn for condition 4 (TO+12) is higher than normally found in CKD and at the high end of the range found in common soils. As noted above, the tolerance of the kiln system for Zn is highly dependent on the chemistry of the raw materials being used, and the input of Zn to the system should be monitored.

VI) Effects on Emissions

A) Dioxins & Furans (D/F)

Results for all test conditions were predominately non-detects at levels well below the proposed MACT limit for new cement kilns. For example, the highest possible emissions rate based on the detection limits achieved was 0.0081 ng/dscm TEQ compared to a proposed limit of 0.20 ng/dscm TEQ.

It is well documented in the literature that dioxin and furan formation in cement kiln systems is largely a function of gas temperatures at the air pollution control device. Therefore it is not expected that the addition of shingle materials would impact D/F emissions.

B) Metals

1) General

As shown in Figures 2 through 7, most apparent differences in metals emissions are at confidence levels that do not meet EPA's generally accepted standard of 95% for statistical significance. In other words, where the confidence level is low, there is a significant probability that the apparent change was due to variations in the testing methods or normal variations in operating conditions. However, for each apparent increase or decrease, an attempt was made to verify whether the change could be attributed to the change in feed material.

2) Beryllium (Be)

Analytical results for Be were all non-detects. No impact of shingle materials on Be emissions could be observed.

3) Cadmium (Cd)

The results for Cd are shown in Figure 2. While the test results show elevated emissions of Cd for Conditions 2 (TO) and 3 (MW), it should be noted that the confidence level of these results (73% and 72%, respectively) is low. Since the cadmium levels in all three shingle materials are nearly identical to the level in the raw meal, it can be concluded that shingle feed has no impact on Cd emissions.

4) Chromium (Cr)

As shown in Figure 3, Cr emissions apparently decreased with the addition of shingle materials. This is an unexpected result, since the chromium content of TO materials and TO+12 materials was somewhat higher than that of the raw meal. However, as above, it should be noted that the confidence level of the difference is relatively low (57% for condition 2 and 92% for conditions 3 and 4). Therefore, it is likely that the apparent decrease in Cr emissions is unrelated to the shingle feed.

5) Hexavalent Chromium (Cr+6)

Analyses for Cr+6 yielded mostly non-detects for all but condition 3 (MW). One of the three test runs for this condition resulted in an emission rate of about five times the other two runs. This result is anomalous and is discussed below. Cr+6 levels in the MW shingle materials were actually less than in the raw meal, and the unit was not operating at a temperature sufficient to cause the formation of hexavalent chromium from trivalent chromium. Therefore it is improbable that the elevated emissions result is related to the shingle feed. Since total chromium emissions were actually lower than baseline, it is likely that the elevated result is due to sample contamination or lab contamination.

6) Copper (Cu)

The results for Cu are shown in Figure 4. The confidence levels of the differences are relatively low (80% for condition 2). While one might anticipate some increase in Cu emissions, it would be expected to occur during condition 3 (MW), since MW materials contain more Cu than the others. However, conditions 3 and 4 show no significant change from the baseline. The elevated result for condition 2 is suspect, since the mass of Cu being fed to the unit during condition 2 was less than for condition 3.

7) Mercury (Hg)

As shown in Figure 5, Hg emissions showed an increase during conditions 3 (MW) and 4 (TO+12), again at relatively low confidence levels (89% and 91%, respectively). The concentration of Hg in shingle materials was less than in raw meal. Therefore, the apparent increase is most probably unrelated to shingle feed.

8) Nickel (Ni)

As shown in Figure 6, Ni emissions apparently decreased with the addition of shingle materials. This is an unexpected result, since the Ni content of shingle materials was somewhat higher than that of the raw meal. The confidence level of the difference is relatively low (60% for condition 2, 90% for condition 3 and 92% for condition 4). Therefore, it is likely that the apparent decrease in Ni emissions is unrelated to the shingle feed.

9) Lead (Pb)

As shown in Figure 7, Pb emissions apparently decreased with the addition of shingle materials. This is an unexpected result, since the Pb content of TO and TO+12 shingle materials was somewhat higher than that of the raw meal. The confidence levels of the differences from the baseline condition are 82% for condition 2 and 90% for conditions 3 and 4.

C) Carbon Monoxide & Total Hydrocarbons (CO & THC)

CO and THC are typically used by EPA as indicators of combustion conditions. EPA has proposed limits of 100 ppm CO and 20 ppm THC to demonstrate good combustion in newly constructed cement kilns.

Use of shingle materials appeared to have no significant impact on CO or THC emissions. Average THC remained below 16 ppm and average CO remained below 100 ppm. During condition 3 (MW), the throat of the calciner plugged, restricting gas flow through the calciner. After cleaning the throat, the upper burners of the calciner were utilized to bring temperatures back to operating range, changing the combustion conditions and temperature profile of the unit. CO during this test condition was about 10% higher than the baseline, but still below 100 ppm.

D) Sulfur Dioxide (SO_2)

As shown in Figure 8, sulfur emissions during the test were extremely low. While SO_2 emissions appeared to decrease with the use of shingles, the confidence level of the differences was low. A sample of stack gas was also analyzed for hydrochloric acid (H_2SO_4) and sulfur trioxide (SO_3) with non-detect results. The use of shingles appeared to have no significant impact on SO_2 emissions.

E) Nitrogen Oxides (NO_x)

NO_x emissions appeared to increase with the use of shingle materials, as shown in Figure 9. This was an unexpected result, and the cause is not clear. As discussed below, the effects on NO_x emissions should be further demonstrated in full scale testing.

F) Hydrogen Chloride (HCl)

While HCl emissions appeared to decrease with the use of shingle materials, the confidence level of the difference is low. It is probable that the apparent decrease is unrelated to the use of the shingle materials.

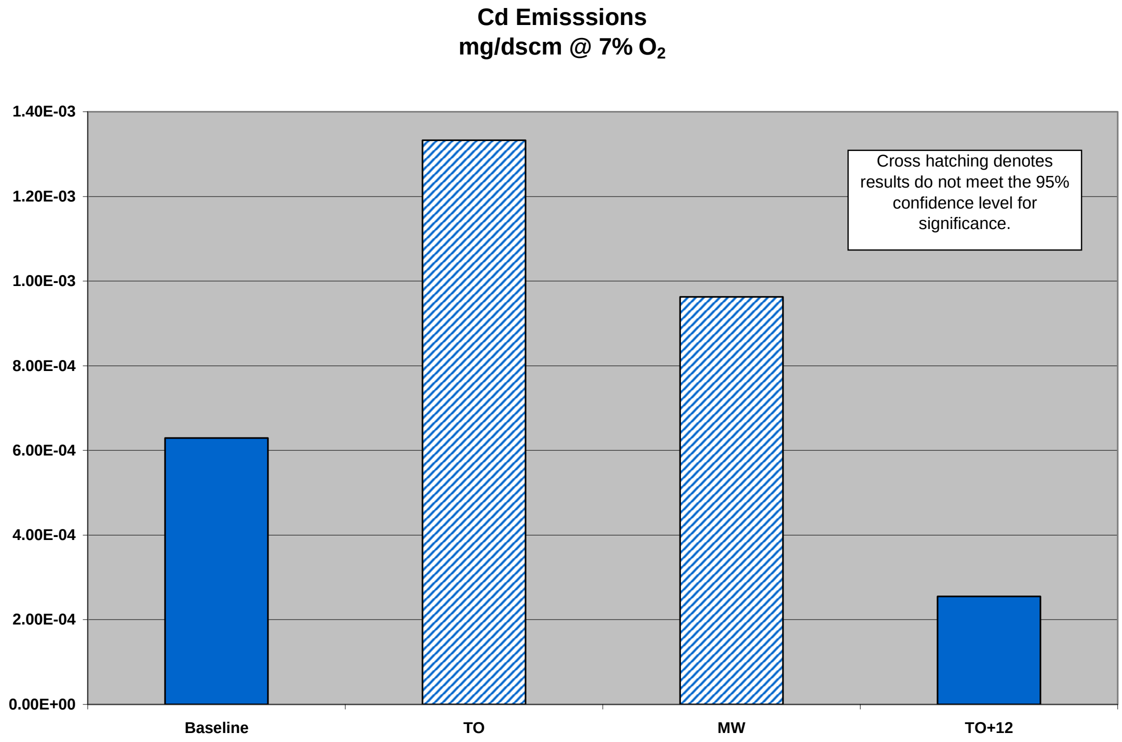
G) Summary of Emissions Effects Compared to Baseline (Condition 1)

Emission Parameter	Condition 2 TO	Condition 3 MW	Condition 4 TO+12
D/F	←→	←→	←→
Metals			
Be	←→	←→	←→
Cd	⇔	⇔	↓Unexplained
Cr	⇔	⇔	⇔
Cr+6	←→	↑ Unexplained	←→
Cu	⇔	⇔	⇔
Hg	←→	⇔	⇔
Ni	⇔	⇔	⇔
Pb	⇔	⇔	⇔
CO	⇔	⇔*see note	⇔
THC	⇔	⇔	⇔
SO_x	⇔	⇔	⇔
NO_x	↑ Unexplained	↑ Unexplained	↑ Unexplained
HCl	⇔	⇔	⇔

⇔ Change was not significant at 95% confidence level
←→ No change was observed
↑ ↓ Increase or decrease was observed

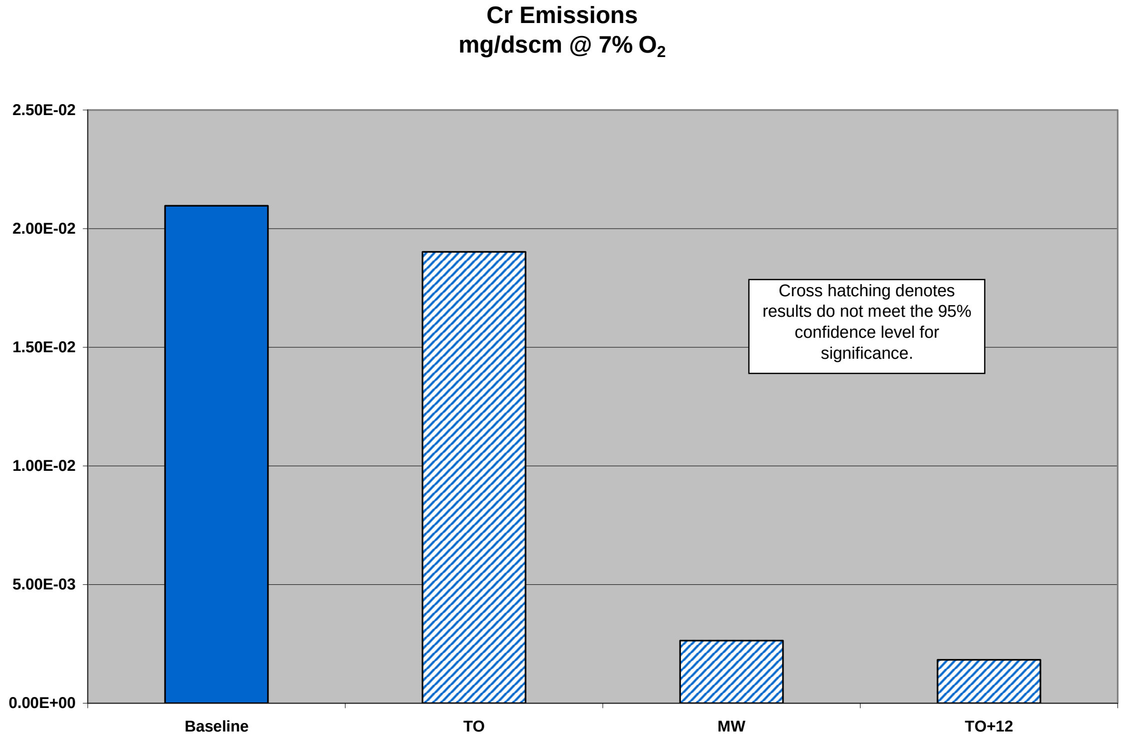
* Using “normalized” data with the baseline outlier removed, an elevation in CO was observed in condition 3. See discussion above.

Table 8



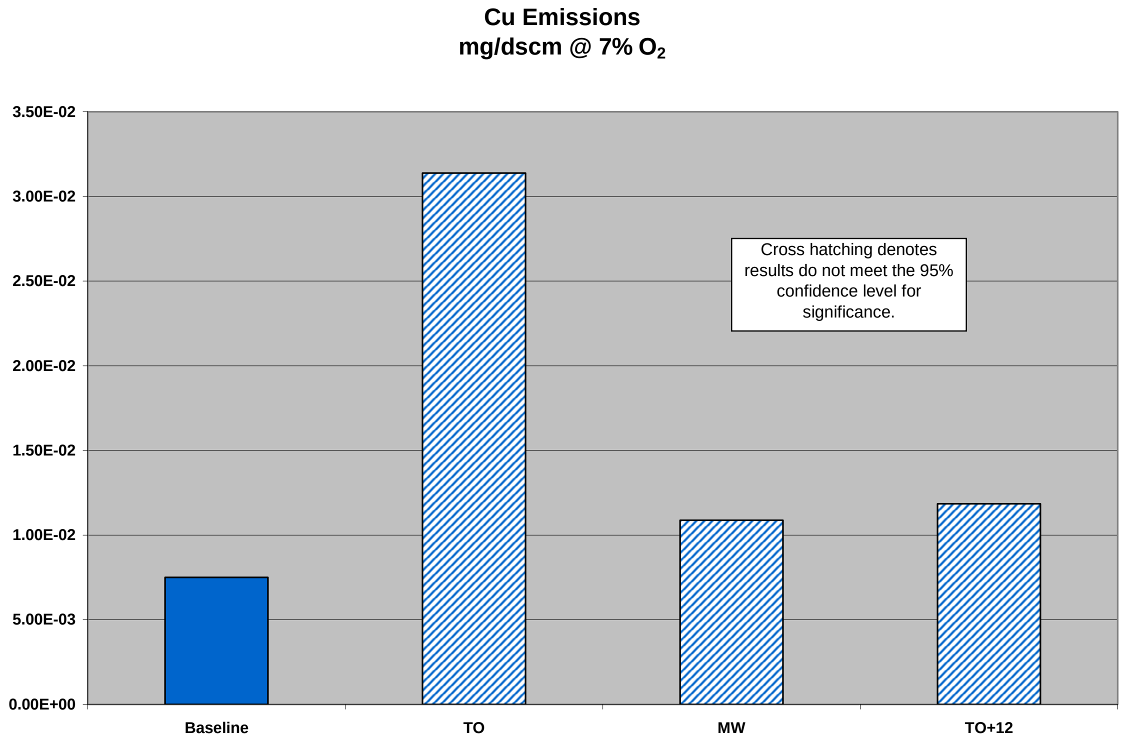
Cross hatching denotes results do not meet the 95% confidence level for significance.

Figure 2



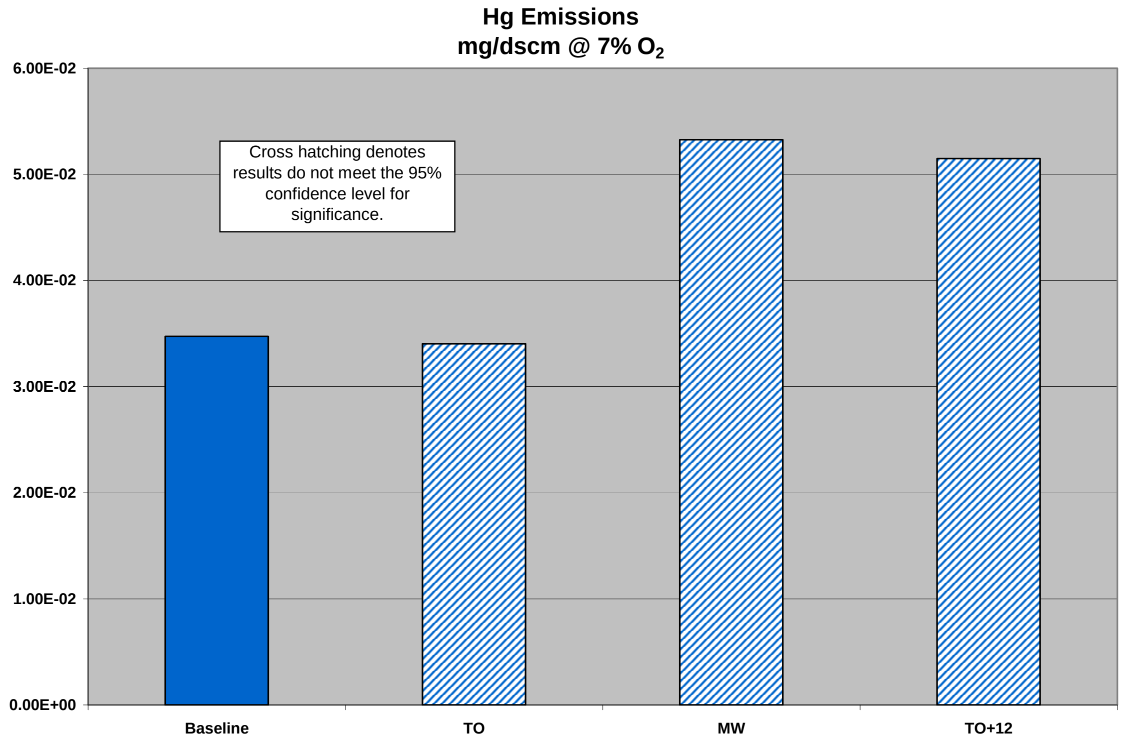
Cross hatching denotes results do not meet the 95% confidence level for significance.

Figure 3



Cross hatching denotes results do not meet the 95% confidence level for significance.

Figure 4



Cross hatching denotes results do not meet the 95% confidence level for significance.

Figure 5

Ni Emissions
mg/dscm @ 7% O_2

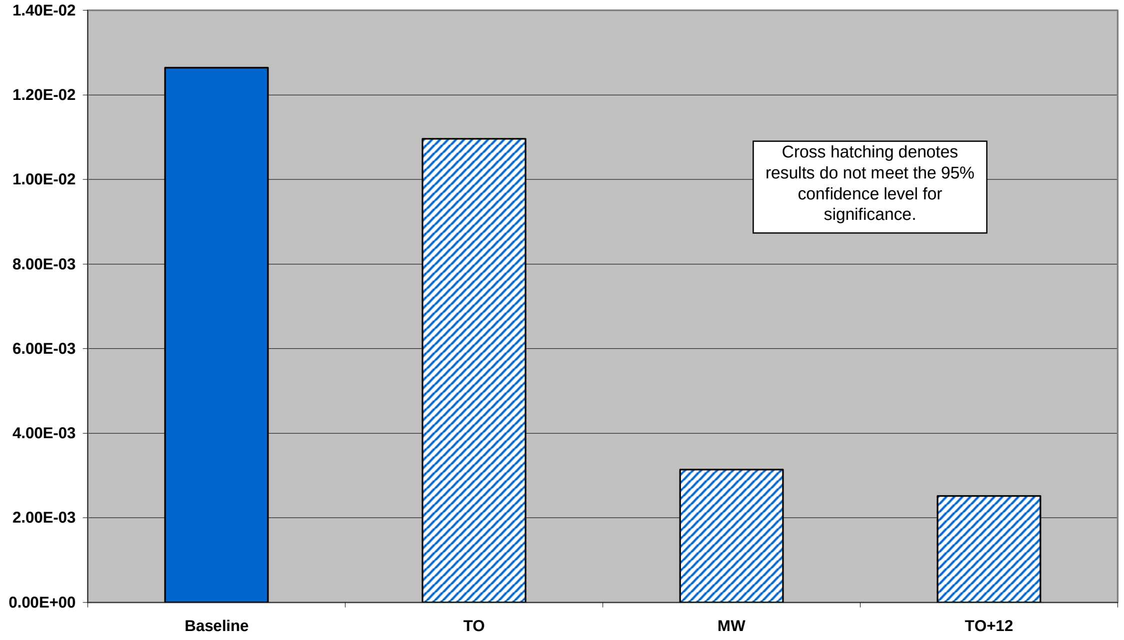


Figure 6

Pb Emissions
mg/dscm @ 7% O_2

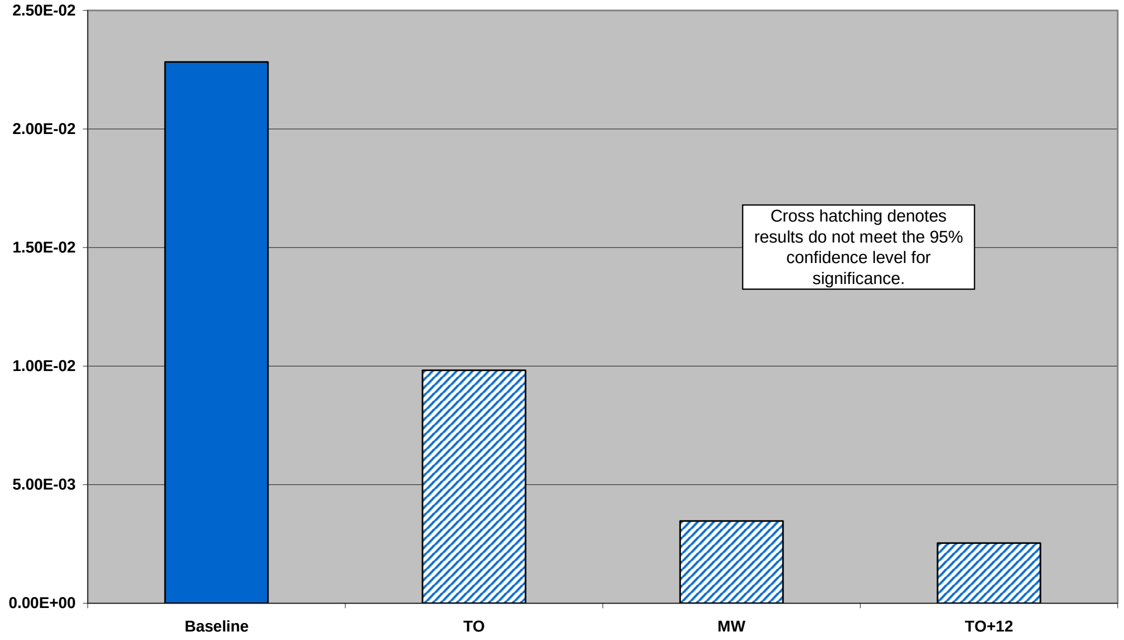


Figure 7

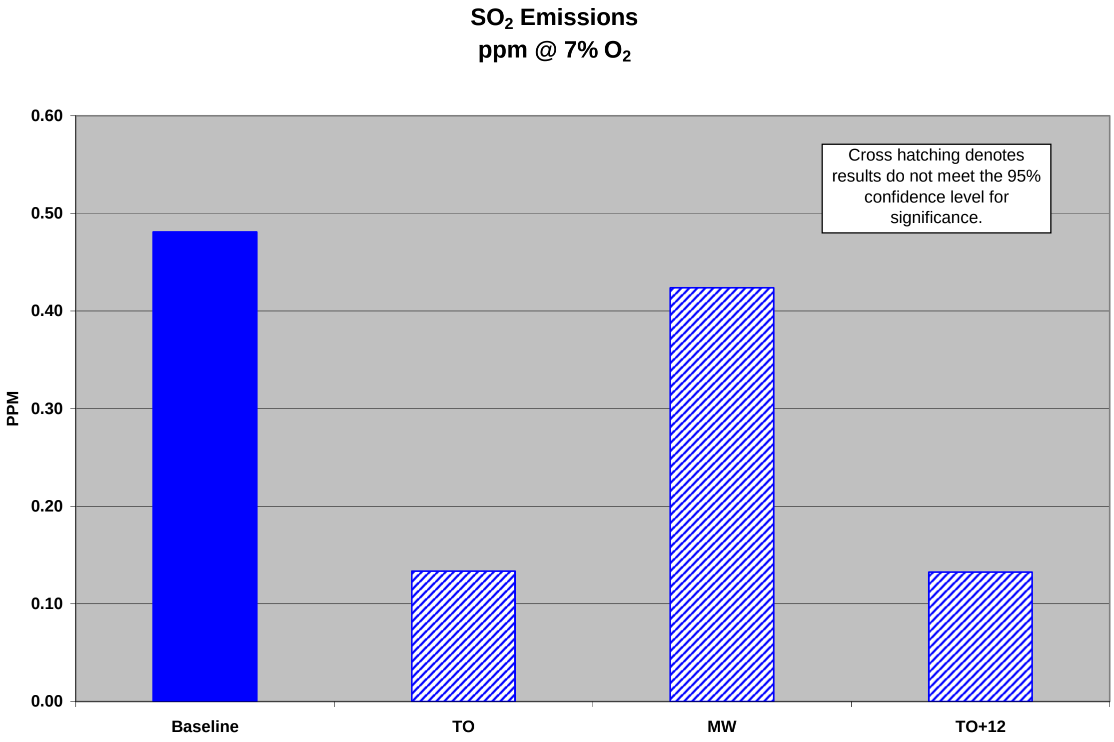


Figure 8

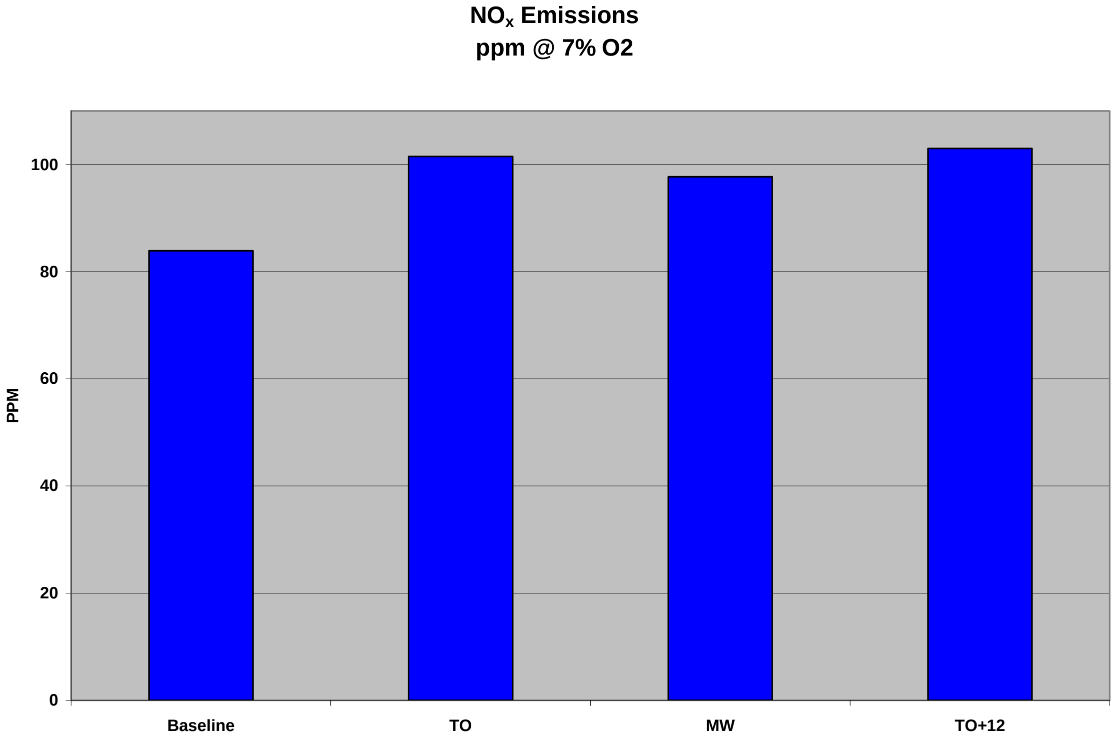


Figure 9

VII) Discussion of Anomalies

As explained above and shown in Tables 4 and 7, a few apparent changes in metals concentrations in the calciner product and in the baghouse fines were greater than can be explained by differences in feed materials. Accurate data on flow rates into and out of the system were not available, but estimated mass balances fail to account for the results. While it is possible that variations in flow rates or feed chemistry could account for the anomalous results, there is insufficient data to support a conclusion.

As shown in Table 8, there are three anomalous results for stack emissions:

- an unexplained decrease in Cd for condition 4 (TO+12),
- an unexplained increase in Cr+6 for condition 3 (MW), and
- increased NO_x for conditions 2, 3 and 4.

As noted in the discussion above, the decrease in Cd for condition 4 and the increase in Cr+6 for condition 3 cannot be explained by differences in feed to the unit. It should be noted that during testing for condition 4, the air to air heat exchanger became plugged. The material cleaned from the unit was a reddish clay material. It is possible that the presence of this material in the exchanger affected results due to movement of the material or baking off of volatile elements.

The increase in NO_x is also difficult to explain. At the operating temperature of the flash calciner, NO_x emissions would be predominately from fuels and raw materials and not from thermal formation. Analyses show the shingle materials contain less than 1% nitrogen compared to zero content in the raw meal. The apparent increase cannot be explained even assuming all of the nitrogen were emitted as NO_x.

As a practical matter, the test results for NO_x from this pilot test are not particularly meaningful relative to a full scale kiln system due to the formation mechanisms and fuels typically used.

VIII) Potential Effects on Cement Manufacturing Operations

A) NO_x

NO_x emissions from a cement kiln system are primarily from thermal formation and from fuels. Depending upon the system, one might expect a decrease in NO_x using shingles in the preheater or precalciner due to a reduction in the flame temperatures at other burner locations. This would be highly dependent on the configuration of the kiln system and the ratio of fuels used at the various firing points. Despite the apparent elevation in NO_x emissions during the pilot test, no increase in NO_x is expected in full scale operations.

B) Chemistry Variations

Significant variations in feed chemistry present severe quality control and operational challenges for cement kiln operations. The pilot test was not of sufficient scale to determine the range of variation in chemistry of shingle materials, but available data show significant variations in SiO_2 and CaO content among various samples. Differences in chemical composition between tear off materials and manufacturing wastes and between screened and unscreened materials make it unlikely that a cement kiln system could accommodate switching between types of materials on a regular basis.

C) Build Up of Materials

In cement plants, build up of sulfur and chlorine containing materials on the walls of production vessels is problematic. During the pilot testing, no build up was observed. Materials that clogged the calciner throat were granular in nature, were not sticky and did not contain problematic sulfur or chlorine compounds. Materials that clogged the air-to-air heat exchanger were clay materials left over from a previous project and were not related to shingle materials.

D) Dropout & Reducing Conditions

During condition 3 (MW) testing, granular materials clogged the throat of the calciner. Based on the appearance, particle size and chemistry of the material, it is likely that these were shingle granules that dropped out of the gas flow. Dropout is a cause for concern in a cement kiln system for two reasons.

First, dropout of material can cause non uniform heating and non uniform feed to the kiln, which could affect quality of the clinker produced or cause problems maintaining stability of the kiln process.

Second, dropout of material can cause localized reducing conditions to develop in the kiln system causing quality problems and increasing sulfur emissions.

It is likely that dropout could be adequately addressed by proper placement of the injection point in a full scale kiln system. The injection point should be located at a point where gas velocity is sufficiently high to keep the material in suspension and at a point where dropout material would not accumulate to cause operational issues. Full scale trials would be required to determine the proper location.

E) Materials Handling

There were no observed handling problems during the pilot test. The design of full scale operations should draw from the handling experience of the shingle processors and others using similar materials (in hot mix asphalt, for example).

IX) Conclusions & Recommendations

The use of chipped shingle materials in cement manufacturing is technically feasible. While the pilot test was not designed to fully simulate the effects of shingles on a kiln system, minimal impacts on emissions and on parameters effecting clinker quality were observed, and no barriers to full scale testing were discovered.

Full scale testing in a cement manufacturing facility would need to be conducted to demonstrate adequate control of chemical variations in the shingle feed and to determine the proper placement of the introduction point. Full scale testing would also be required to determine the maximum feasible usage rate for shingle materials.

Appendix B

The Fate of Asphalt Shingles Containing < 1% Asbestos in Cement Kilns

ESI ENVIRONMENTAL STUDIES INTERNATIONAL

THE FATE OF ASPHALT SHINGLES CONTAINING <1% CHRYSOTILE ASBESTOS IN CEMENT KILNS.

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Revised: February 18, 2008
August 10, 2007

Executive Summary

Chrysotile asbestos is irreversibly altered by the thermal conditions of a cement kiln, including a brief heating time at 1,000 or 1,400°C, whether in the presence or absence of cement kiln feed or asphalt shingle. These results are consistent with the known thermal properties of chrysotile asbestos and similar results would be expected for the other asbestos fiber-types.

Introduction

Approximately 11 million tons of asphalt shingle waste is generated in the United States each year. The vast majority (>85%) of the material consists of residential tear-off shingles, while the remaining material is waste from asphalt shingle manufacturing plants. About 2,337,500 homes in the United States are re-roofed annually, with each home generating about 4 tons of roof tear-off material. Currently these materials are being disposed of in landfills where they undergo minimal degradation within a human lifetime. Finding uses for these asphalt shingles would have two benefits:

1. *Reduce reliance on virgin minerals and fossil fuels.*

2. *Allow better use of the ever more limited and costly landfill capacity.*

At least two alternatives to landfill disposal of asphalt shingle have been considered:

1. Adding the used shingles to new paving asphalt in a program referred to as "roofs to roads"; and
2. Our proposal, to use shingles as both an alternative energy and raw material source for cement kilns.

Prior to introduction into the cement kilns, the used shingles would be reduced in size to approximately 3/8 inches, using a variation of wood chipping technology. Asphalt shingles provide energy value when combusted. In addition, they contain calcium carbonate and silica, minerals normally used as components of the kiln feed. The principal source of amorphous silica in residential roofing is fiberglass, which reacts at lower temperatures than crystalline quartz, the form of reasonably pure silica most common in the cement making process. The US Cement Industry produces about 100,000,000 short tons per year of cement from approximately 1.5 times that amount of starting feed material. About one third of the starting (unheated) material is lost as carbon dioxide gas when the calcium carbonate is calcined. A reasonable estimate is that about 30% of the current US cement production capacity could utilize shingles as a significant percentage of its kiln starting material.

The amount of asphalt in shingles has been reduced with time, and now shingles contain between 20-25% asphalt; the other components in decreasing percentage by weight are filler (limestone, a mixture of calcium and calcium magnesium carbonates), granules (painted granite rocks and coal slag), mat (fiber glass), back dust (limestone powder or silica) and adhesive (Table 1). The lifetime of an asphalt shingle varies; the national average age of roofs replaced was 19.5 years in 2004 (Worms, 2006). Given the current national average, most of the roofing asphalt shingles currently in place today were

installed after 1986 and only about 0.3% of the shingles recently recycled in a “roof to roads” program have been found to contain asbestos (Technical Report, 2003).
From about 1963 to 1979 some manufacturers used chrysotile asbestos, the only asbestos fiber-type used, as a fiber reinforcer in some asphalt roofing shingles. When used, the total chrysotile asbestos content was less than 1% for residential asphalt roofing shingles. By-weight, asphalt shingles constitute 80-90% of a typical residential roof tear-off. Two other components which might contain asbestos are underlayment (10-15% chrysotile asbestos) and mastics (5-25%) (USEPA Purple Book, 1985). When used, these materials are more commonly incorporated in commercial (built-up) roofing. Asbestos-containing roofing products are rarely used in residential roofing, and we expect the percentage of asbestos containing shingles coming off roofs to further decline with the passage of time.

Physico-Chemical Properties of Chrysotile

Crystal Structure: Chrysotile asbestos is one of the serpentine minerals; they are structurally characterized by the presence of two sheets, one a silicate sheet and the other a non-silicate sheet called brucite (Figure 1a). The most important member of the serpentine group is chrysotile asbestos; one of the six minerals regulated under the asbestos standard in the United States and the only asbestos mineral in the serpentine group of minerals. This asbestos fiber-type was historically the one most commonly used in commerce, and the only asbestos fiber-type still commercially available, or ever used, in residential roofing materials (Virta, 2004). Global production of chrysotile asbestos remains fairly constant at 2 million tons per annum, while US consumption has decreased from a high of 719,000 tons in 1973 to just 3,450 tons in 2004 (Ross and Virta, 2001; Virta 2004). Only Grade 7 chrysotile asbestos, which is the shortest and least expensive asbestos fiber grade, is used in the fabrication of roofing products. Approximately 43% of the current chrysotile asbestos consumption in the US goes into commercial and residential roofing products, although none is used in asphalt shingles. The remaining 57% of the current chrysotile asbestos consumed is used for non-roofing-related products where adequate replacements have not been found.

Chrysotile asbestos consists of two component layers, a tetrahedral layer $(Si_2O_5)_n^{2n}$ and an octahedral layer $[Mg (OH)_2]$ (Figure 1a). The basic units of the tetrahedral layer are six-membered rings, having pseudo-hexagonal or trigonal symmetry (Figure 1b). The chrysotile growth extends in two dimensions to form an infinite sheet. The octahedral layer is similar, formed by magnesium octahedrally coordinated with oxygen and hydroxyl groups. This is commonly referred to as the brucite layer. The dimensions of the two sheets differ. Attention is generally focused on the b-axis of the octahedral sheet, which is larger than the same axial direction in the tetrahedral sheet (9.45Å compared with 9.15Å). The mechanism used by chrysotile to compensate for this mismatch is curling, with the tetrahedral or silicate sheet on the inside and the octahedral or Mg sheet on the outside. The hexagonal sheet is rotated and twisted to accommodate the apical O-O distance in the tetrahedral sheet with the O-O distance in the octahedral sheet. Chrysotile asbestos is a curled fibrillar version of a double sheeted crystal structure (Figure 1b). This structural accommodation imparts thermal and chemical instability to the mineral and results in chrysotile asbestos having a rolled structure with a hollow tube at the center (Figure 2).

Thermal Decomposition: The thermal decomposition of chrysotile asbestos (in the absence of an excess of CaO) follows a two-step process – dehydroxylation over the temperature range of 550-680° C with a maximum loss of structural water at about 660° C, followed by a re-crystallization of the amorphous serpentine into the olivine mineral forsterite in the range of 810-820° C (Figure 3). The decomposition is not affected by the type of gaseous atmosphere and the resulting products are forsterite and silica according to the following chemical reactions (Figure 4):

$$\mathbf{2Mg_3[Si_2O_5]\,(OH)_4 \rightarrow 3Mg_2SiO_4 + SiO_2 + 4H_2O}$$

Chrysotile Asbestos → Forsterite + Silica + Water

As the temperature continues to increase, forsterite will become better crystallized and begin to react with silica to form enstatite as the temperature increases over 1,000° C according to the following chemical reaction:

$$\mathbf{Mg_2SiO_4 + SiO_2 \rightarrow 2MgSiO_3}$$

Forsterite + Silica → Enstatite

As large excesses of calcium are present in the cement kiln these two magnesium containing phases -forsterite and enstatite- may be present only in trace amounts. This will be discussed in more detail below.

After the thermal breakdown of the chrysotile asbestos, which begins at about 500° C and is completed by about 660° C, the fibrous nature of the mineral is profoundly changed. It has lost the high tensile strength associated with asbestos and the fibrous morphology exists only as a ghost structure having little or no mechanical strength, due to the loss of the chrysotile asbestos structure. The incipient fiber will change to a non-fibrous particulate with the application of minimal mechanical force. The forsterite, silica and enstatite are non-fibrous.

Cement Kiln Considerations

In a cement kiln, the silica, forsterite, and enstatite resulting from the thermal decomposition of the asbestos will be present in a cement kiln with a strong excess of lime (CaO) at temperatures above about 850-950° C. Lime will react with the siliceous portion of chrysotile to generate belite. The overall reaction is summarized in the following:

$$\mathbf{2CaO + Mg_2SiO_4 \rightarrow \underset{Belite}{Ca_2SiO_4} + \underset{Periclase}{2\,MgO}}$$

$$\mathbf{2CaO + SiO_2 \rightarrow \underset{Belite}{Ca_2SiO_4}}$$

As earlier noted, the forms of silica indicated are far more reactive with lime than is quartz, or other crystalline modifications of silica such as cristobalite or tridymite. Therefore, the rate of the reaction whereby the various silica forms are converted to belite (a dicalcium silicate found in Portland cement clinker with the chemical formula Ca_2SiO_4)

is expected to be very fast. The formation of belite from lime and forsterite, or from lime and silica, is highly exothermic as well.

The mineral name for belite is larnite, a metamorphic mineral encountered in high temperature contact of limestone with igneous intrusions (Thrush, 1968). The lifetimes, therefore, of the initial decomposition products of chrysotile asbestos before they react to form belite, will occur in a small fraction of the kiln retention time. Once belite is formed, the reaction is irreversible under the conditions of the kiln. Much of the belite will be subsequently converted to alite (Ca_3SiO_5) by excess lime present, and will therefore be an additional step away from the precursor chrysotile asbestos.

Chrysotile asbestos cannot survive the thermal conditions of a cement-manufacturing kiln (Figure 5). Our goal was to demonstrate experimentally that chrysotile asbestos would undergo thermal decomposition and conversion to forsterite and then to calcium silicates over the operating temperature of the cement kiln (Figure 3 & 4, Table 2). This analytical method uses x-rays of a specific wavelength (λ) to identify the various atomic layers (referred to as d-spacing), which can be used to uniquely identify crystallized materials. The observable is x-ray intensity as a function of the angle at which the x-rays scan the sample. The angle ($\sin\theta$) at which the peaks occur are related to the distance between the atomic layers or d-spacing (d) of the crystal by using Bragg's Law.

$$\mathbf{n\lambda = 2d\ sin\theta}$$

The powder x-ray diffraction pattern of chrysotile is shown in Figure 6. The reflection with the maximum intensity occurs around 12.5° 2θ corresponding to a d-spacing of 7.36Å (Wicks 2000). Briefly heating the chrysotile to 1,000°C causes a high temperature chemical reaction in which chrysotile is altered to the mineral forsterite (Figure 7). The most intense peak associated with the chrysotile structure is no longer present confirming the chrysotile is no longer present. Although the reaction also produces silica, it is not crystalline and therefore does not have a diffraction pattern.

Samples 1 & 3 were not thermally treated while Samples 2 & 4-7 were thermally treated at 1,000°C for 20 minutes and Sample 8 was heated for 20 minutes at 1,400°C. The concentration of chrysotile in the binary mixture was about 7%.

(1) Chrysotile Asbestos - the powder x-ray diffraction pattern is shown in Figure 6.

(2) Chrysotile Asbestos heated to 1,000°C changes structure to become forsterite the powder diffraction pattern in Figure 7 shows this change and the most intense peak in the chrysotile pattern (the 100% peak) is no longer present.

(3) Cement Kiln Feed as is.

(4) Cement Kiln Feed calcined to 1,000°C.

(5). Asphalt shingle heated to 1,000°C.

(6). Cement Kiln Feed and 7% Chrysotile Asbestos calcined to 1,000°C(the 100% chrysotile peak is no longer present; see Figure 8).

(7). Asphalt Shingle and 7% Chrysotile Asbestos heated to 1,000°C (the 100% chrysotile peak is no longer present; see Figure 8).

(8). Asphalt Shingle and 7% Chrysotile Asbestos heated to 1,400°C without kiln feed.

The thermally induced changes in these three materials (chrysotile asbestos, cement kiln feed, asphalt shingle) singly and as binary mixtures with the kiln feed or asphalt shingle with chrysotile asbestos were followed using continuous scan powder x-ray diffraction. The 100% reflection for the starting chrysotile in Figure 7 is no longer present in the binary mixtures of chrysotile and kiln feed or chrysotile and asphalt shingles after briefly heating to 1,000°C for 20 minutes.

The structural characteristic of the starting materials (chrysotile asbestos and cement kiln feed) and the six samples after thermal treatment are summarized below:

Starting Crystalline Phase	**Crystalline Phases Present**
Chrysotile Asbestos† (Unheated).	Chrysotile Asbestos (Figure 6)
Chrysotile Asbestos (Heated) (for 20 minutes to 1,000°C).	Forsterite (Figure 7)
Cement Kiln Feed (Unheated)	Calcite, Quartz, Dolomite, Muscovite or Illite and a potassium feldspar (probably microcline)
Cement Kiln Feed Calcined (or heated) (for 20 minutes to 1,000°C).	Lime, Quartz, Periclase, and Belite
Asphalt shingle heated (for 20 minutes at 1,000°C).	Sodium-rich Feldspar (probably Albite or Anorthoclase)
Cement Kiln Feed and Chrysotile Asbestos calcined (or heated) (for 20 minutes at 1,000°C).	Calcium Oxide, belite and Quartz (no Chrysotile Asbestos peaks or intense forsterite peak are present)
Shingle and Chrysotile Asbestos heated (for 20 minutes at 1,000°C).	Quartz, Feldspar and possibly Lime. Chrysotile Asbestos or Forsterite Peaks were not observed.
Shingle and Chrysotile Asbestos heated without kiln feed (for 20 minutes at 1,400°C).	Glassy non-crystalline lacking the crystallinity needed for analysis by powder x-ray diffraction. Chrysotile Asbestos or Forsterite Peaks were not observed.

†The chrysotile sample used was Union International for Control of Cancer (UICC) Standard reference sample of Canadian chrysotile called UICC B.

Conclusions

Chrysotile asbestos does not survive the conditions of a cement kiln, including a heating regimen to 1,000 or 1,400°C, whether in the presence or absence of cement kiln feed or asphalt shingle (Figure 6,7,8). These results are consistent with the known thermal properties of chrysotile asbestos and similar results would be expected for the other asbestos fiber-types (Table 2).

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Table 1. The composition of the currently marketed asphalt shingles.

20-25% Asphalt	32-42% Filler	28-42% Granules	2-15% Mat	3-6% Back Dust	0.2-2% Adhesives
Provides waterproofing properties.	Typically limestone materials. Crushed rock and fly ash may have been used historically but only in limited production.	Painted granite rocks for exposed surface color and coal slag for the head lay (non-exposed portion of the shingle that is overlapped during installation).	Majority of shingles currently being manufactured (and since the 1980s) has a fiberglass mat. Prior to 1980 the mat was heavy cellulose or cotton based material and in the 1970s cotton rag was used.	Usually ground limestone-type material or silica sand. Other materials such as coal slag were used in small quantities.	Asphalt-based materials, perhaps modified with small concentrations of fillers such as SBS rubber.

Table 2. Thermal Properties of the Asbestos Minerals.

Thermal Property	Chrysotile	Crocidolite	Amosite	Anthophyllite	Actinolite	Tremolite
Decomposition Temperature (in ºCelsius)	450-700º	400-600º	600-800º	600-850º	950-1040º	620-960º
Fusion Temperature (in ºCelsius) for Residual Material	1,500º	1,200º	1,400º	1,450º	1,315º	1,400º

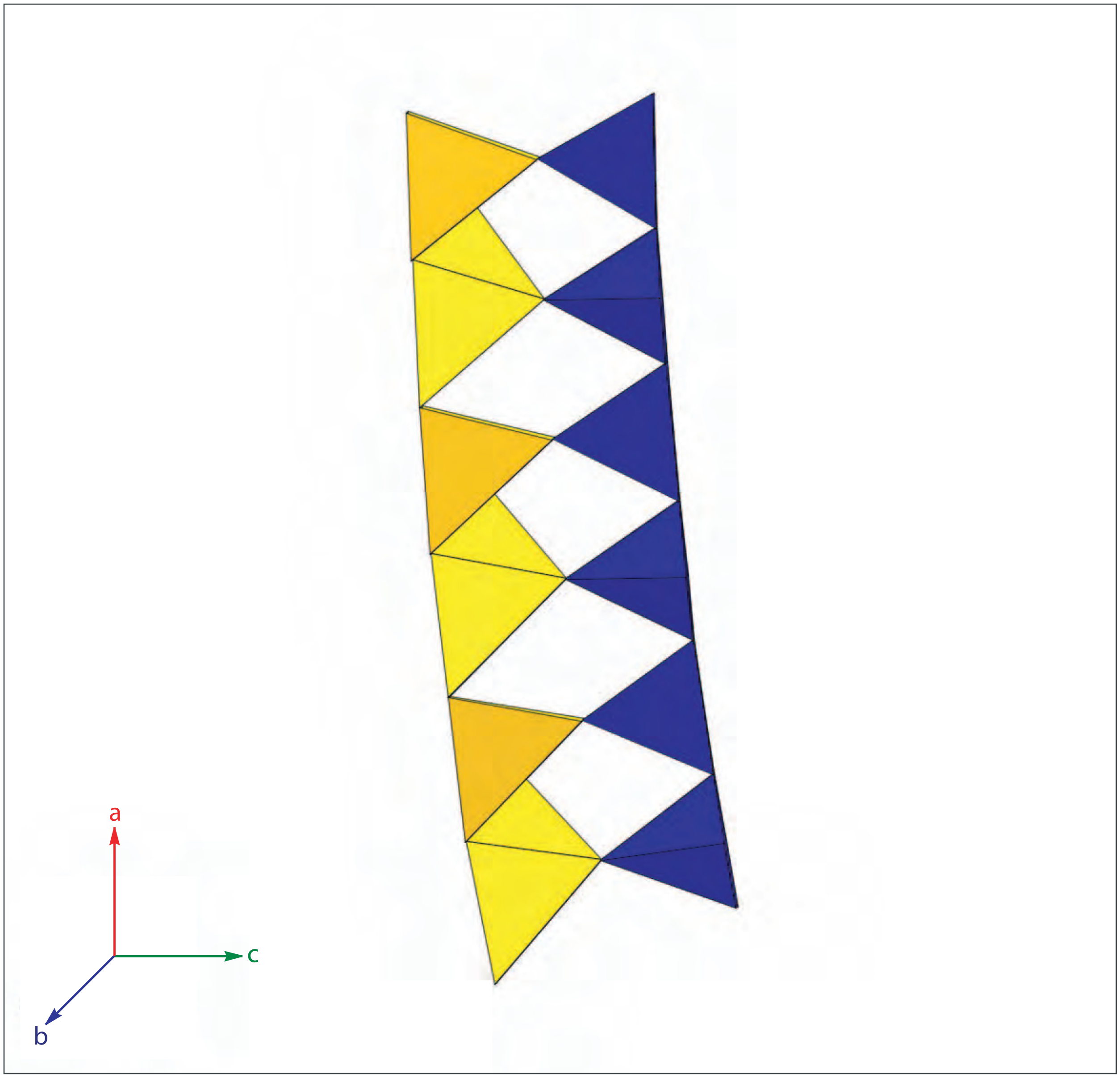

Figure 1a. The polyhedral model depicts the two sheets of the serpentine mineral chrysotile asbestos. The silicate tetrahedral layer is shown in blue, and the octahedral brucite layer in yellow. The mismatch between these two layers accounts for the curvature in the chrysotile asbestos causing a structural strain.

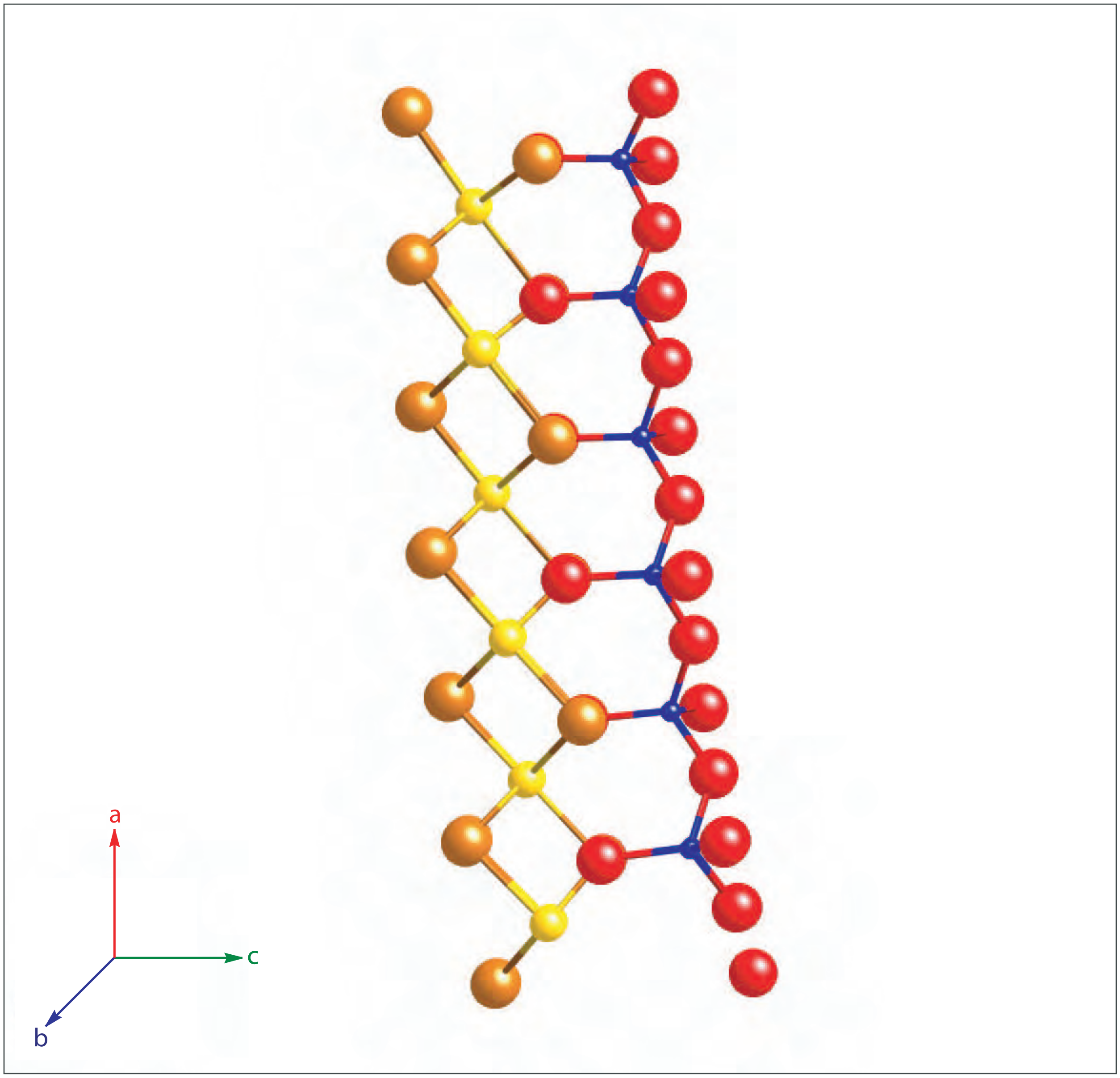

Figure 1b. The ball and stick model better displays the chrysotile asbestos chemical formula $2Mg_3[Si_2O_5]\ (OH)_4$. The silicon and magnesium cations are blue and yellow respectively. The anions -oxygen and hydroxyl (OH) are red and brown respectively.

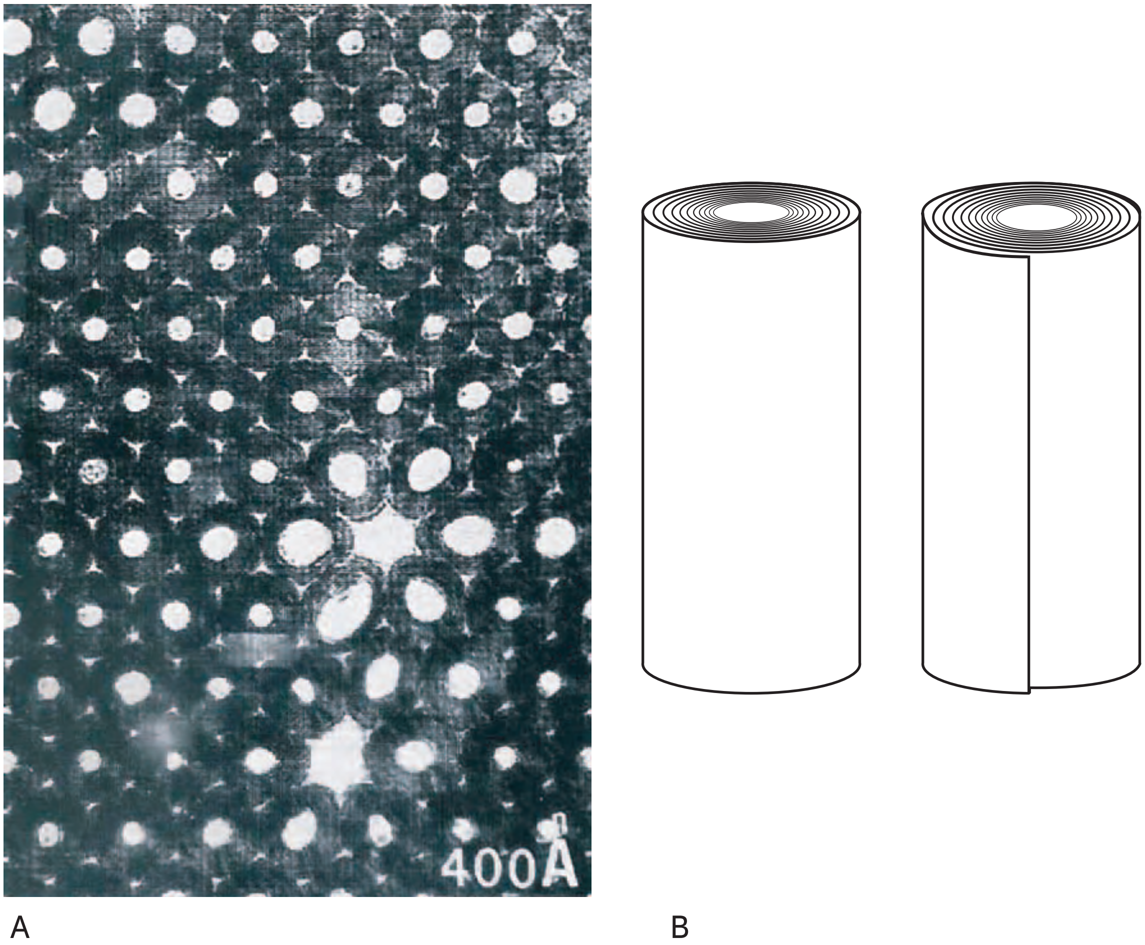

Figure 2. Morphology of chrysotile fibrils A. Transmission electron photomicrograph of a cross-section of chrysotile fibrils (adapted from Baronnet A: Polymorphism and stacking disorders. In: Busek PR (ed) Mineral Reactions on the Atomic Scale: Transmission Electron Microscopy. Reviews in Mineralogy, Volume 27, Washington, DC, 1992, Mineralogy Society of America. B. Schematic representation of the cylindrical and spiral fibril (Adapted from Veblen DR & Wylie AG: Mineralogy of amphiboles and 1:1 layer silicates. In: Guthrie GD & Mossman BT (eds) Health effects of Mineral Dust. Reviews in Mineralogy, Volume 28, Washington DC, 1993, Mineralogical Society of America.

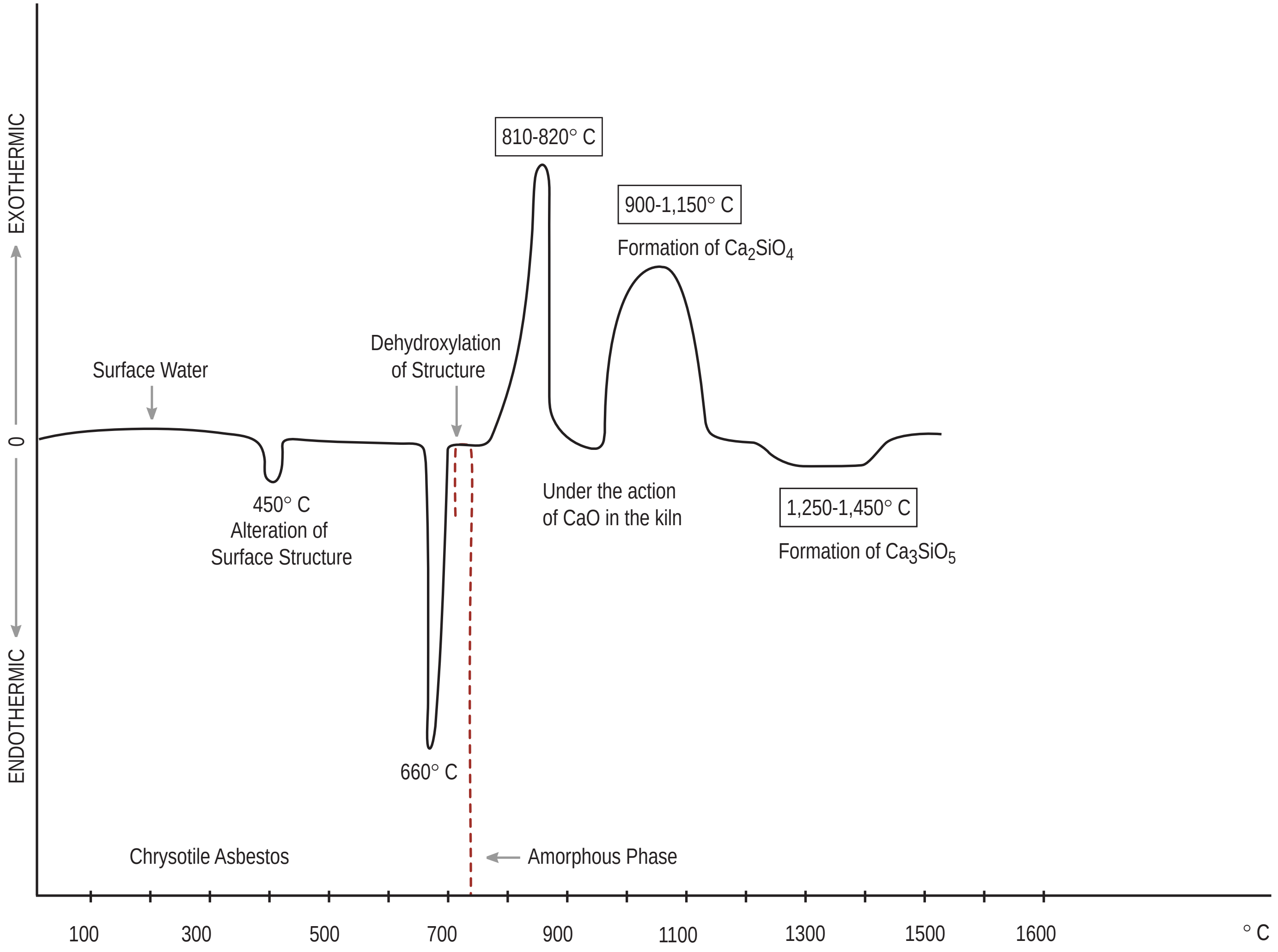

Figure 3. Typical Differential Thermal Analysis (DTA) of chrysotile asbestos over the temperature range at which a cement kiln operates. Note the thermal decomposition of chrysotile asbestos at 810-820° C. Due to the action of a large excess of calcium oxide (CaO) the silicate released when the chrysotile decomposes will form Ca_2SiO_4 and react again to form Ca_3SiO_5 at higher temperatures in an endothermic reaction.

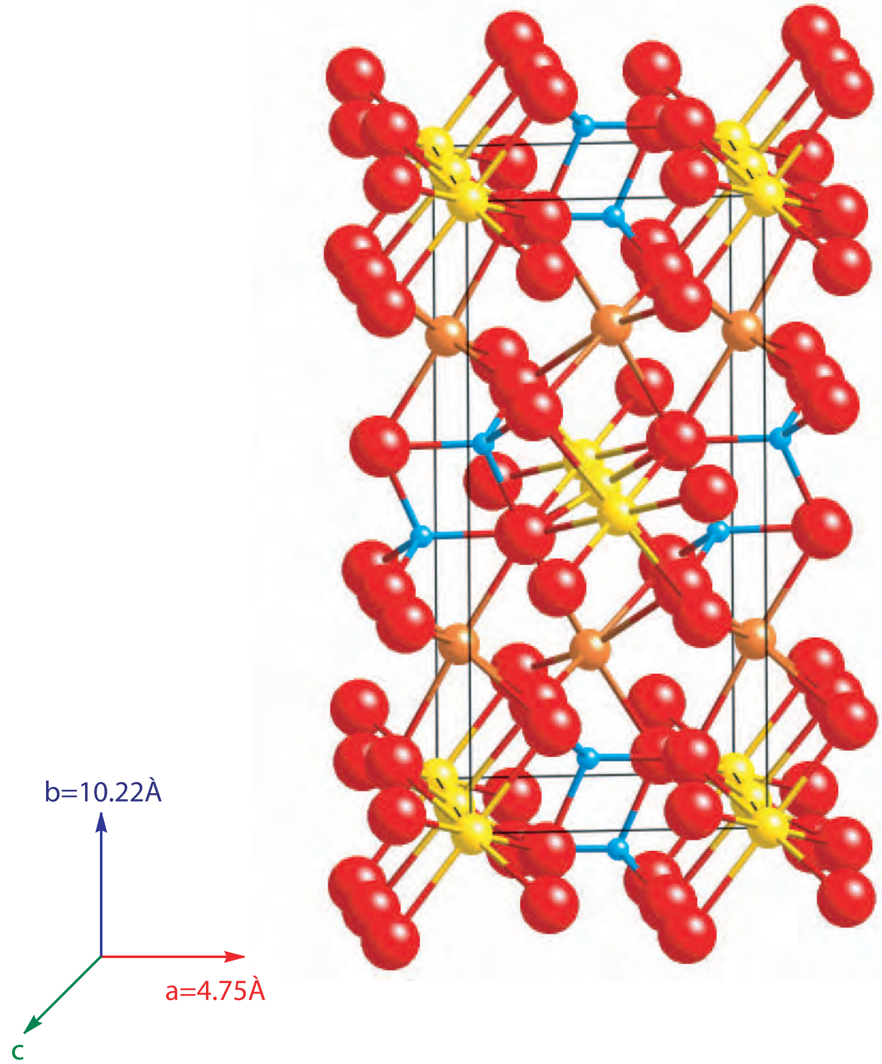

Figure 4. When heated over the range of 800-850° C chrysotiles asbestos undergoes thermal decomposition. If the heating continues well crystallized forsterite becomes detectable over 1,000° C. The model depict oxygen as red, silicon as yellow while M1 and M2 sites are blue and brown respectively. The M sites are populated by magnesium**.**

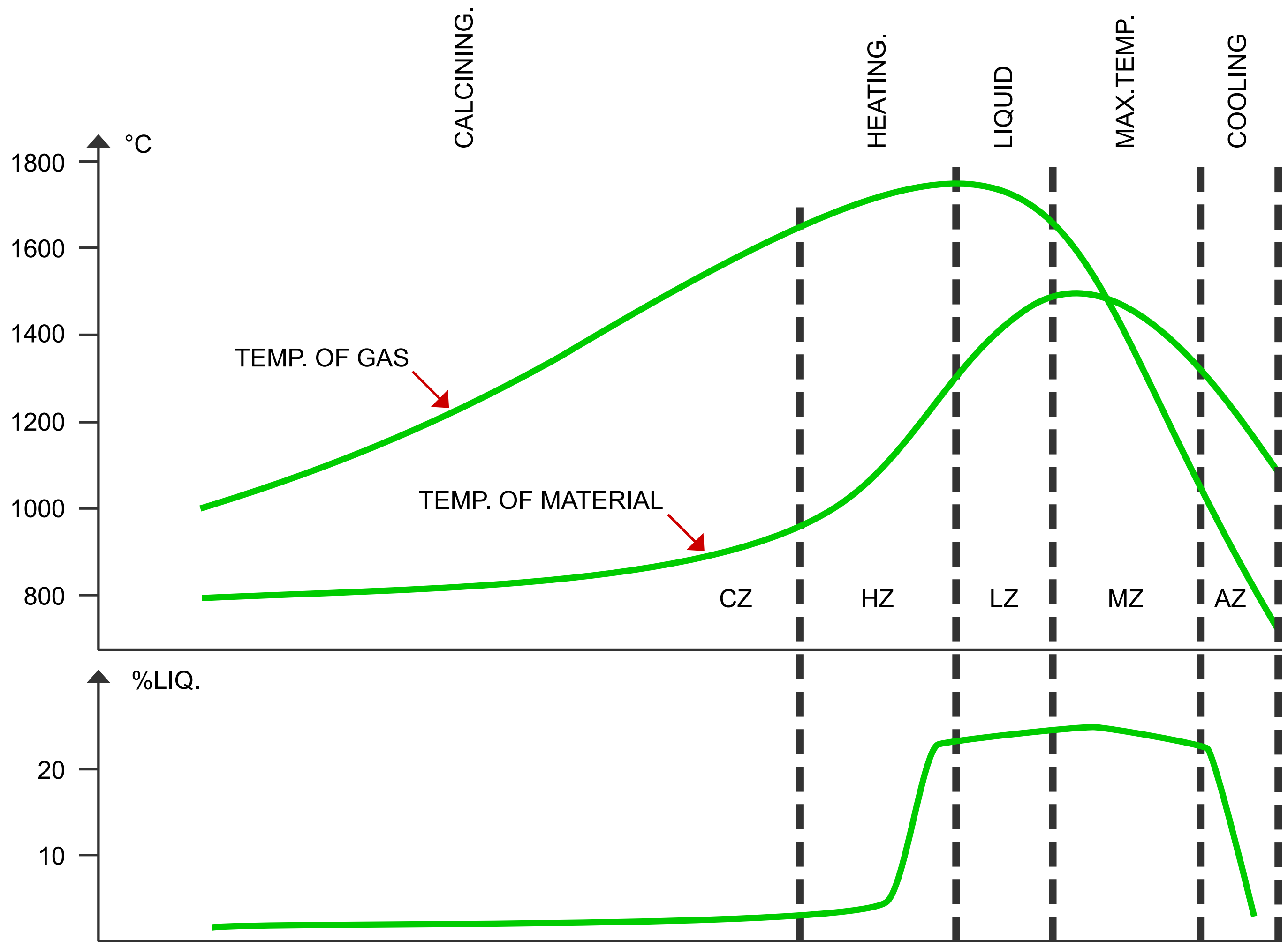

Figure 5. The temperatures associated with the various zones of a modern cement kiln. Chrysotile asbestos is not stable above 660ºC and new crystalline phases begin to form above 800ºC.

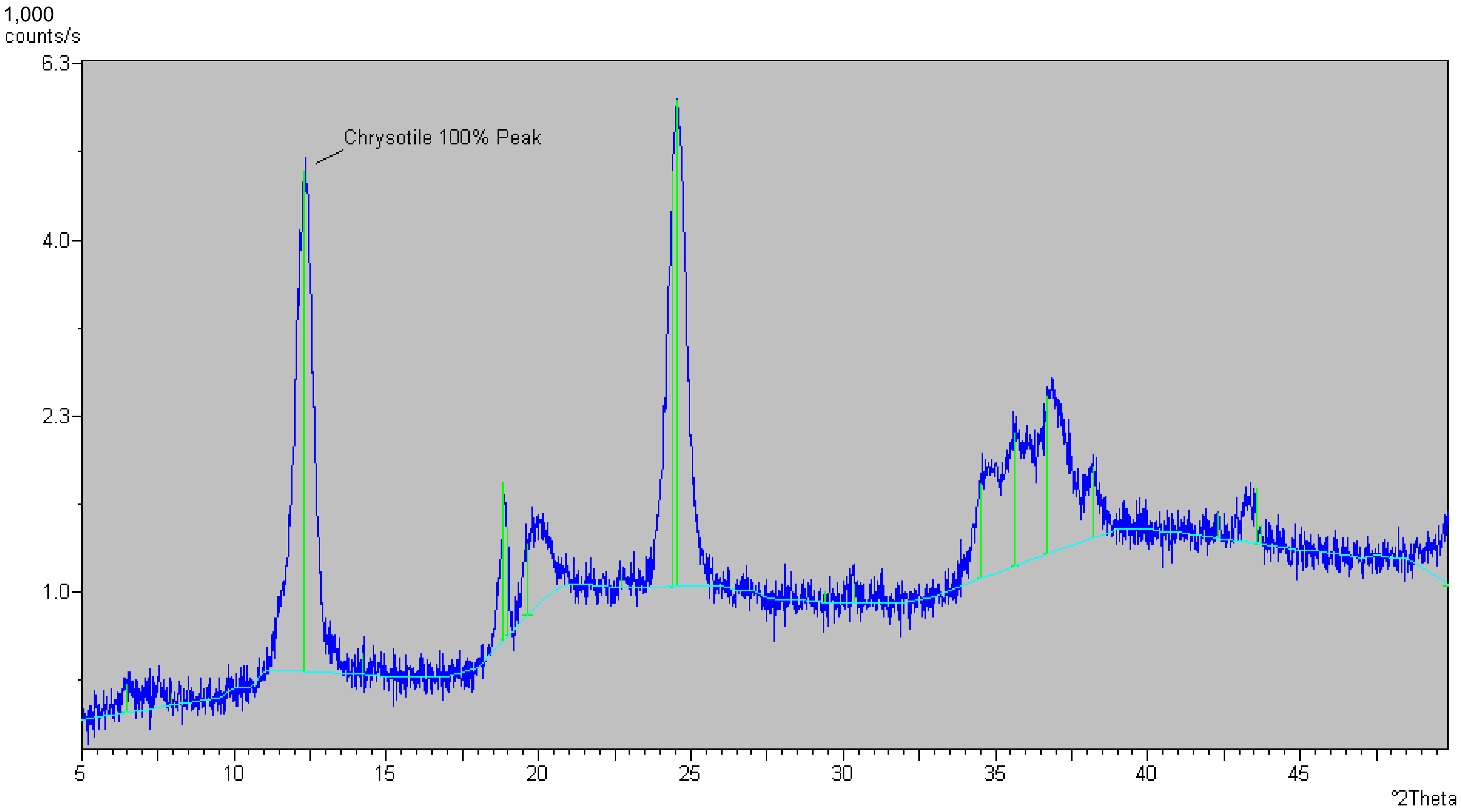

Figure 6. Powder x-ray diffraction pattern of the starting material – chrysotile asbestos is shown; note the 100% peak at around 12° 2Theta.

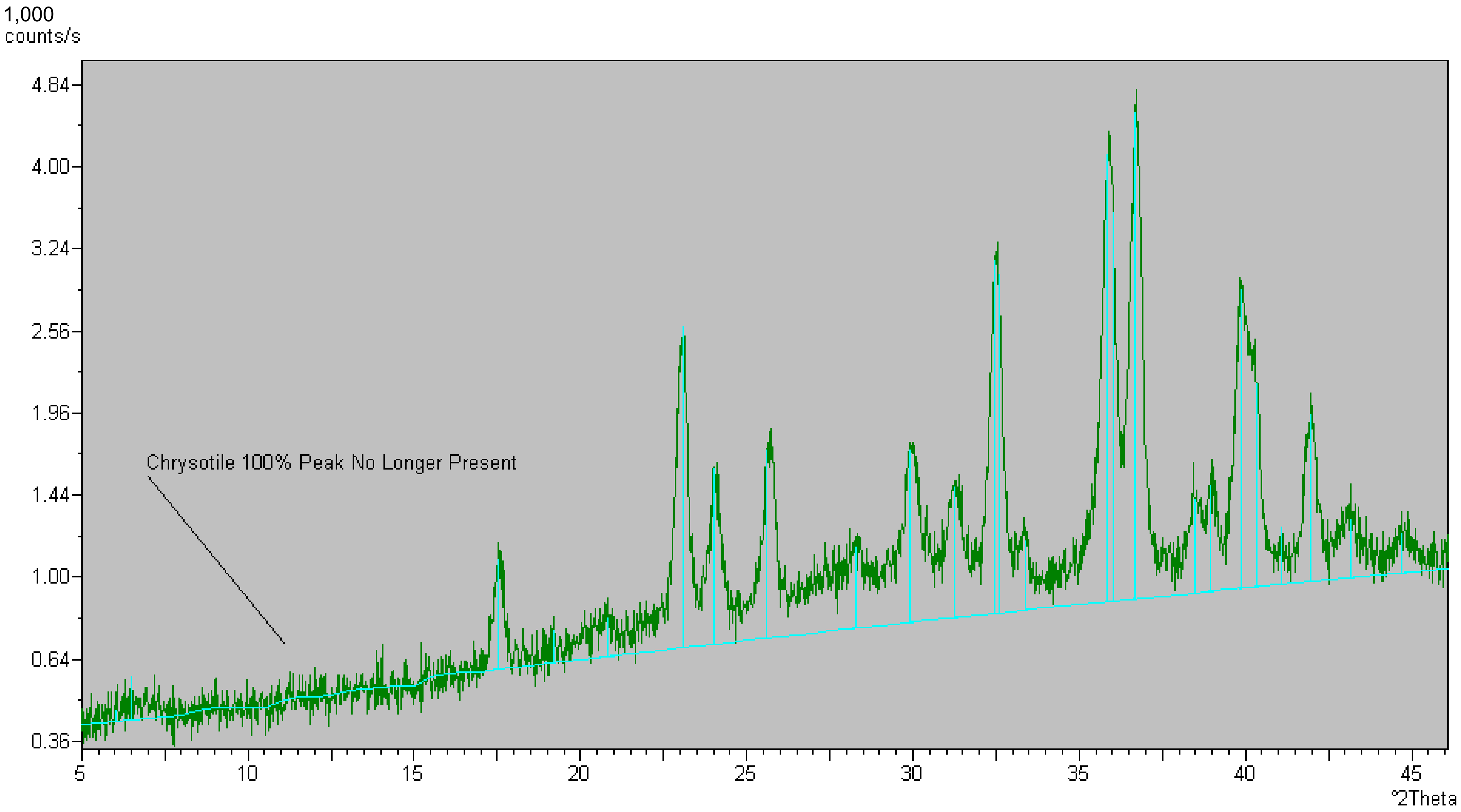

Figure 7. Powder x-ray diffraction pattern of forsterite the new mineral formed from chrysotile asbestos by a high temperature reaction.

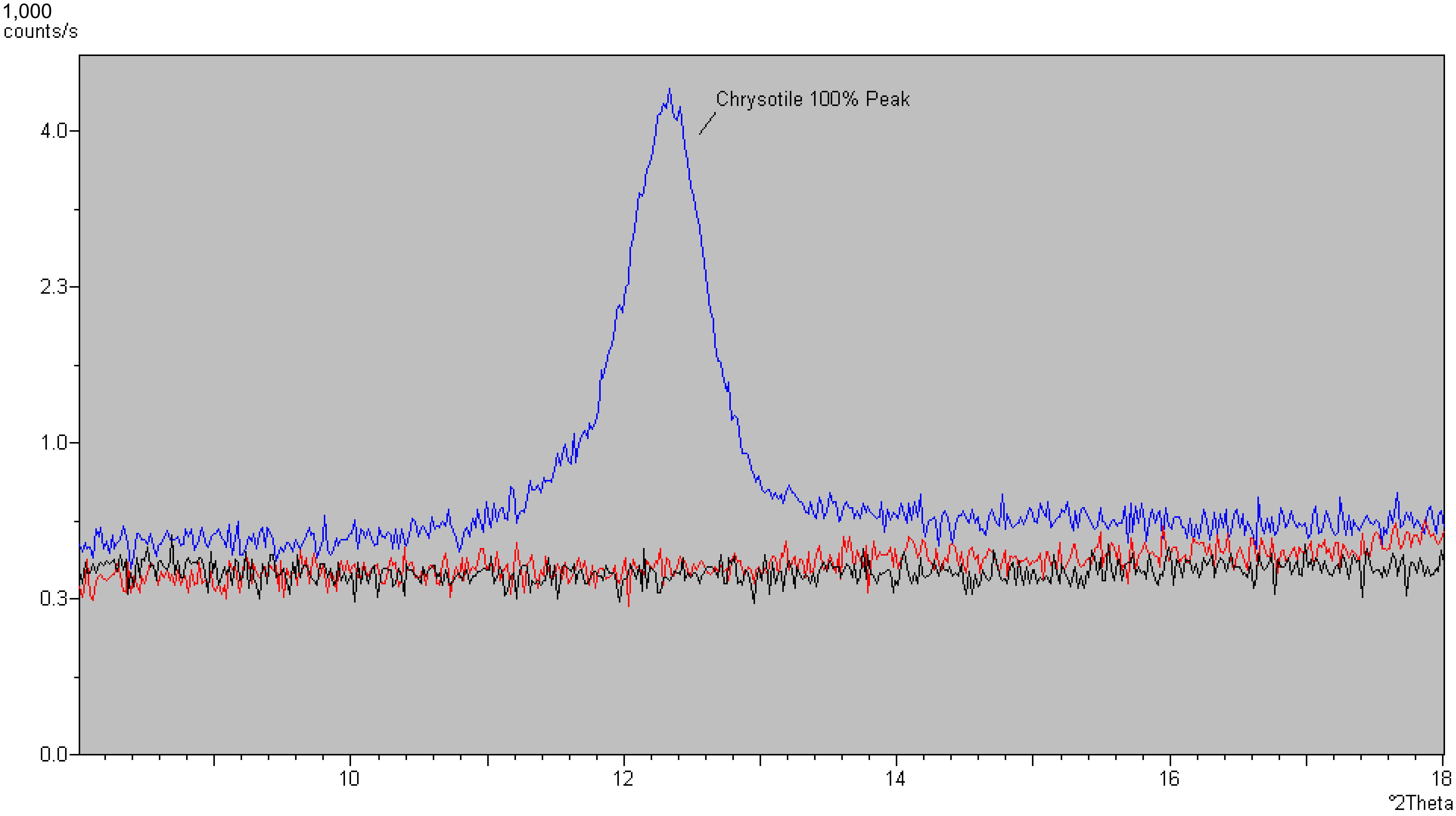

Figure 8. The 100% peak for the starting material chrysotile is shown. This reflection is absent from the binary mixtures of chrysotile with either kiln feed or asphalt shingle (shown below in red and black).

Appendix C

Technical Feasibility Report
Use of Asphalt Roofing Materials
In CFB Boilers

Technical Feasibility Report
Use of Asphalt Roofing Materials
In Circulating Fluidized Bed Boilers

Pilot Test Of Shingle Tear-Off Waste In A Small Commercial CFB Boiler (15,000 lbs steam/hr)

Conducted By
Owens Corning & Fayette Thermal, LLC
June – October, 2007

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04/28/2008

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Executive Summary

As part of Owens Corning's commitment to sustainable development, this premier manufacturer of asphalt roofing shingles in the United States is investigating beneficial uses for waste shingle materials, both manufacturing wastes and wastes arising from tear-off of shingles as roofs are replaced.

One possible use for these shingle materials is as a fuel and partial limestone replacement for circulating fluidized bed (CFB) boilers. In the combustion chamber, air is passed upward through a series of nozzles above which solid fuels are fed. The upward velocity of the air suspends the fuel as it burns and carries the heat upward to a heat exchanger. As the fuel burns, smaller particles are carried upward with the gas flow, through a separator and circulated back into the combustion chamber. Fine ash is removed from the gases prior to exhaust.

CFB boilers can be designed to accommodate a wide variety of solid fuels. Emissions of sulfur compounds are typically controlled by the addition of ground limestone with the fuels. NO_x emissions are controlled by maintaining a stable, uniform bed temperature and a temperature profile favorable for staged combustion.

After a small scale trial in August of 2006 demonstrated that SO_2 and NO_x emissions reductions could be expected from the use of recycled asphalt shingles for about 20% of the total fuel by weight, full scale trials were conducted during the period from June through October of 2007 at the Fayette Thermal steam production facility near East Millsboro, Pennsylvania. This facility operates two CFB boilers capable of producing 15,000 lbs per hour of steam each. One boiler is typically on line at any given time, with the other in standby mode.

Two types of recycled asphalt shingles were used in the trials: 1) TO material, which was chipped tear off wastes screened to a top size of about 1 inch, and 2) TO+12 material which was tear off wastes chipped to a top size of about $^3/_8$ inch and screened to remove most of the shingle granules (TO+12). Only materials found to be free of asbestos were used in these trials.

The first few loads of TO shingle materials delivered to the Fayette site contained significant amounts of oversize material which caused problems in the feed equipment and also caused instability in the fluidized bed. Operational problems unrelated to the use of shingles also occurred throughout the test period, limiting the amount of useful data that could be collected. In addition, fluctuations in the ambient relative humidity are suspected to have caused corresponding fluctuations in emissions making meaningful comparisons of emissions data challenging.

Due to the physical configuration of the feed equipment, uniform feeding of the shingle materials to achieve the desired ratio of coal to shingle materials was difficult, and the percentage of shingles fed as fuel may be subject to a wide margin of error.

Substituting shingle materials for up to 40% of the fuel by weight, the stability of these particular boilers was improved due to the combustion characteristics of the shingle materials. Emissions data collected using 20% and 40% roofing shingle tear-off waste indicate that significant reductions in NO_x and SO_2 emissions can be achieved when incorporating these materials into the traditional fuel stream. No adverse effects on boiler operation or ash quality were noted. No differences were noted between operations using TO and those using TO+12, however it is anticipated that a higher percentage of granules may increase abrasion in the boiler over time.

It is recommended that further operations be conducted using shingles as fuel in order to optimize the boiler operation, determine long term effects and determine any modifications to the boiler system necessary for use on an ongoing basis. It is also recommended that controlled testing be done to determine whether the mineral content of shingle materials has potential to replace the limestone used in the boiler to control SO_2 emissions.

I. Introduction

In a typical circulating fluidized bed (CFB) boiler, fuel is introduced into the combustion chamber where it is suspended in a stream of upwardly flowing air. As the fuel burns, finer particles are carried upward with the hot gases through a heat exchanger into a solids separator or baghouse. A portion of the solids are circulated back into the combustion chamber.

This recirculation of solids results in a high residence time of the fuel particles in the combustor and a relatively high transfer of heat to the exchanger. Inert material included with the fuel can actually improve heat transfer as the heated particles circulate, keeping the required boiler temperature low. Given these characteristics, combustion temperatures are low compared to powdered coal boilers, resulting in lower NO_x emissions.

The high residence time allows the boiler to utilize coarse fuel. Limestone may also be mixed with the fuel to control SO_2 emissions, eliminating the need for separate scrubbing systems. The ability of a CFB boiler to utilize sulfur bearing fuel, high inclusion of inert material and coarse particle size makes it an attractive technology for using waste fuels.

Tear off wastes from residential asphalt shingle roofs typically contain the following materials:

Asphalt Shingles	-	80 to 90%
Wood	-	0 to 10%
Tar Paper	-	5 to 13%
Metals	-	less than 1%
Other	-	less than 1%

The asphalt shingles in turn contain 16 to 25% asphalt coating along with mineral content from the fiberglass mat, granules, filler and “backdust.” The filler and backdust typically contain limestone and silica sand.

In order to evaluate whether asphalt shingles from roofing tear-offs could be utilized as fuel in a CFB boiler, a trial was conducted utilizing the Fayette Thermal CFB boiler facility near East Millsboro, Pennsylvania. The purpose of the trial was to determine the effects shingle materials would have on:

- CO, NO_x and SO_2 emissions,
- Ash quality, and
- Boiler facility operation

A simplified schematic of the Fayette Thermal CFB boiler facility utilized for this trial is shown in Figure 1. The facility is comprised of two CFB boilers along with the associated ancillary equipment necessary to handle fuels, limestone and ash. Each boiler is capable of producing 15,000 pounds of steam per hour. One boiler is typically on line at any given time, while the other is held in standby mode.

The boilers were designed specifically for this installation by Spin Heat, LLC. and later modified by Power Consultants, Inc. The steam is provided to an institutional facility nearby for use in heating, cooling and domestic water heating.

The boilers typically burn bituminous coal waste with the following specifications:

Size	< $^{3}/_{8}$ inch
Moisture	< 12%
Sulfur	< 1.2%
Ash	< 20%
Heat Value	≥ 9,000 BTU/lb (ASTM 3286)

In accordance with environmental permits, 127 lbs of limestone are fed with each ton of coal consumed to control sulfur emissions.

As shown in Figure 1, the ground limestone is fed onto the top of a drag conveyor (point A). Two screw conveyors from the feed hoppers discharge into a common feed point onto the top of the drag conveyor, downstream of the limestone feed point (point B).

The drag conveyor then conveys the limestone and fuel mixture into two day bins on each boiler (point C). Feed to the day bins is intermittent, controlled by high and low limit indicators on the day bins. The day bins deliver the limestone and fuel mixture to the combustion chamber via variable speed screw conveyors.

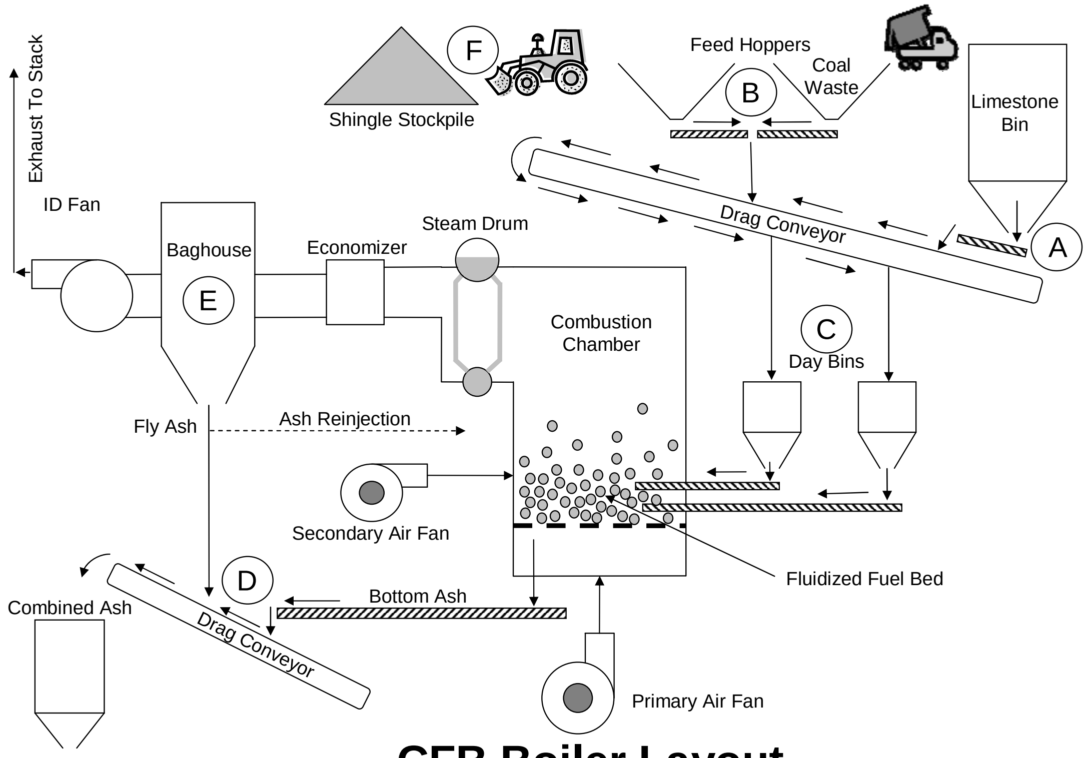
Ash is removed from the bottom of the combustion chamber by a water cooled screw conveyor (point D) and discharged to a drag conveyor leading to the ash silo.

Gases and particulates passing through the heat exchanger and economizer (another heat exchanger used to preheat feed water) enter a baghouse (point E) where the fine ash and particulate are captured. From the baghouse hopper, these solids are either circulated back into the combustion chamber or fed into the drag conveyor with the bottom ash.

For the purposes of these tests, chipped tear off shingle waste materials were delivered to the site in 25 ton dump trailers. The shingles were stored outside in a covered stockpile (point F) until needed and transported to one of the feed hoppers with a front end loader. Thus, one feed hopper fed normal coal fuel while the other fed shingle materials.

While the boilers routinely meet the emissions standards for CO, NO_x and SO_2 set forth in their operating permit, emissions have been higher than what the boiler designer had indicated could be achieved. Fayette Thermal personnel estimated that, according to the boiler designer's information, there was potential to reduce emissions 15 to 20%.

By boiler industry standards, these boilers are quite small and unique in design. Due to the nature of the institutional facility design and operation, steam demand is highly erratic and fluctuates over a wide range. The system does not have much surge capacity, and the boilers must respond quickly to changes in the steam conditions. This combination of small size, erratic demand and quick response makes stable operation challenging, and exploration of alternative fuels that would have a positive impact on emissions and boiler stability is part of an ongoing effort to improve boiler performance and costs of operation.



CFB Boiler Layout

Figure 1

II. Description of the Test

A. Prior Testing: August, 2006

In early August of 2006, a small scale pilot test was conducted to determine whether the use of waste asphalt roofing shingles in the Fayette CFB boilers was feasible. In that testing, shingle materials were fed into the feed hopper screw conveyor manually from buckets. Addition of shingles up to 20% of the fuel by weight resulted in no adverse effects. In fact, according to a test report issued by Fayette Thermal, SO_2, NO_x and CO_2 emissions all improved with the use of shingle materials and no adverse impact on ash quality was noted. In addition, the bed temperature was reduced while maintaining adequate steam flow and pressure. Based on these results, a full scale test using shingle materials for up to 40% of the fuel (by weight) was suggested.

B. Full Scale Test: June – October, 2007

Two types of recycled asphalt shingle materials were evaluated for use in the CFB boilers during the full scale test. The first type was roofing tear-off wastes chipped to a maximum size of about 1 inch. This material is referred to as “unprocessed” material in Fayette Thermal’s report and is referred to as TO material in this report. The second type was similar, but was chipped to a top size of about 3/8 inch and screened to remove most of the shingle granules. This material is referred to as “processed” material in Fayette Thermal’s report and as TO+12 in this report. Material specifications are included in Exhibit A.

The plan for the test was to establish baseline data for emissions and ash quality during normal operations, and to compare these data to corresponding measurements while burning up to 50% of each type of material.

Shingle materials were delivered to the site in 25 ton dump trailers and stockpiled on the ground. When needed, the materials were reclaimed from the stockpile via a front end loader.

During normal operation, coal is dumped directly into the feed hoppers (near point B in Figure 1). In order to evaluate the effect of shingle materials, one feed hopper was emptied and shingle materials were placed into this hopper by the end loader. Thus, one hopper continued to feed normal coal fuel while the other fed shingle materials. During the testing period, the rate of limestone addition was held constant at the same volumetric rate as during normal operations, a rate roughly equivalent to 127 pounds of limestone per ton of fuel used.

The screw conveyors from the feed hoppers to the drag conveyor are constant speed screws, so control of the feed rate of shingles was accomplished by partial closing of the knife gate at the hopper discharge into the screw. Difficulties associated with this are addressed in the next section.

The change from normal fuel to a mixture containing shingles was not instantaneous. The transition typically took about a day to accomplish in order to insure that the day bins were delivering the mixed fuel consistently. Additional transition time was also required to allow the fluidized bed to stabilize with the new mixture of fuel.

The actual testing timeline was as follows:

Time Period	Activity
June 25	Collect baseline data without shingles
June 26	Begin feeding 20% TO materials
June 27	Collect data using 20% TO materials
June 28 – 30	Continue use of 20% TO until instability due to oversize pieces cause shutdown
July 1 – 7	Startup of other boiler, attempt 30% TO. Emissions analyzers malfunction.
July 16	Repaired analyzers available. Begin stabilizing without shingles.
July 16 – Aug 7	Various stability & equipment issues prevent testing.
Aug 8	Begin baseline testing without shingles.
Aug 9	Lightning strike causes outage.
Aug 13 – 16	Startup
Aug 17	Ash drag chain failure causes outage.
Aug 20 – Sept 5	Boiler inspections & startups.
Sept 7 – 13	Stabilizing operation without shingles.
Sept 14	Begin transition to 40% TO shingles.
Sept 15 – 17	Power outages cause restart of boilers.
Sept 18	Stabilizing operation without shingles.
Sept 19	Ramping up to 40% TO shingles.
Sept 20 – 24	Collect data at 40% TO shingles.
Sept 25 – 30	Transition to TO+12 shingles.
Oct 1 – 5	Collect data at 40% TO+12 shingles.

Table 1

III. Challenges During the Testing

Several challenges arose during the testing period, and are discussed as follows:

A. Oversize Shingle Materials

During the initial test period from June 24 to June 30, the TO shingle materials delivered to the site contained a considerable amount of oversize pieces. As shown in Figure 2, the oversize pieces were up to 8 inches and generally thin flat pieces of roofing materials.

The oversize pieces caused problems in three areas: 1) physical feeding through the equipment, 2) disruption of the fluidized bed in the boiler and 3) unburned residue formed in the combustion chamber.

Clogging of the feed equipment caused by the oversize material exacerbated the difficulty in controlling the feed ratios as discussed below. However it is the disruption in bed stability that eventually required the initial test to be terminated. The unburned residue in the combustion chamber was described by operating personnel as “a big blob of tarry mess in the bottom of the boiler, which took a lot of time and effort to clean out.”

The oversize material on site was observed by Owens Corning personnel on June 29, and subsequent loads delivered were within specifications without the oversize pieces. Operating personnel on site separated the stockpile containing oversize pieces and formed a new stockpile with material delivered after June 29. Subsequently, no further issues relating to oversize materials or residue were noted.

Oversize Pieces
Figure 2

B. Control of Feed Proportions

All of the fuel and limestone feeding conveyors at the Fayette Thermal facility are volumetric feeders (screw conveyors and drag link conveyors). Except for the variable speed screws feeding fuel from the day bins into the combustion chamber, all of the conveyors are of the constant speed type. Therefore, the control of feed rates from the limestone bin and from the fuel feed hoppers to the drag conveyor is accomplished by opening or closing the gates at the bin or hopper discharges. This arrangement caused difficulty achieving and maintaining the desired ratios of shingles to normal fuel in the fuel mixture.

In order to achieve the desired proportions, the densities of the waste coal and shingle materials were first compared by weighing five gallon buckets of each. According to Fayette Thermal's records, the coal density was found to be approximately 19% less than the density of the shingle materials. The desired proportions by weight were then converted to volumetric ratios as follows:

% Coal / % Shingles by Weight	**% Coal / % Shingles by Volume**
80 / 20	83.2 / 16.8
70 / 30	74.2 / 25.8
60 / 40	64.9 / 35.1

Table 2

The knife gate at the shingle hopper discharge was then partially opened as necessary to achieve these proportions determined by visually observing the extent to which the shingle screw conveyor was filled (shown in Figure 3) while the coal screw conveyor was operated at full capacity. With the shingle knife gate partially closed, flow to the screw was erratic and air lances and prods were used to maintain flow.

Shingle Feed Screw
Figure 3

Since the screw conveyors discharge at a common point into the drag conveyor, it was not possible to accurately verify the actual weight ratios being fed. Therefore, it should be noted that the feed ratios shown in the results data are approximate only and are subject to a high degree of uncertainty.

C. Co-Mingling of Materials

Shingle materials delivered to the test site can be classified into three categories. The first category consists of the first few (2 or 3) truckloads of shingle TO materials which contained oversize pieces. Materials in this category that were not consumed during the testing period of June 24 to June 30 were set aside as scrap to be used as fill materials on site roadways and storage areas.

The second category consists of the remaining 5 or 6 truckloads of on-specification (no oversize pieces) TO materials delivered after June 29. The third category consists of about 8 truckloads of TO+12 materials (sieved to remove most of the shingle granules).

According to Fayette Thermal's report of the testing, category 2 materials (on-spec TO) were used for the test period of September 19 through 24, and category 3 materials (TO+12) were used for the test period of September 25 through October 5. However, during a site visit on August 17, the stockpile was found to be consolidated, with most of the material observable around the edges being category 3 materials. The pile was covered at the time, so it is not clear whether the middle of the pile contained identifiable category 2 materials, or whether they had been entirely co-mingled.

While this co-mingling of materials raises some uncertainty about the extent to which the test period of September 19 through 24 was conducted with TO materials, TO+12 materials or co-mingled materials, it is clear that testing in June was conducted using TO materials and testing during October was conducted using TO+12 materials. Meaningful comparisons of the differences in emissions among the three categories of materials are hampered by the variations in baseline emissions due to relative humidity as discussed below. However, facility operators observed no differences in operations between the use of TO and TO+12.

D. Operational Problems

Several operational problems occurred during the test period, limiting the amount of meaningful data that could be collected. The majority of these problems can be classified as stability issues or equipment issues.

1. Stability Issues – Due to the boiler and steam delivery system design and the nature of the facility to which the steam is provided, steam demand is erratic and control of the boiler is challenging. Operating personnel indicate that even under ideal circumstances, it takes 48 to 72 hours to stabilize the fluidized bed and properly balance the system. Rapid changes in steam demand, fuel or combustion conditions upset the system balance. This instability results in a high number of variables affecting emissions and operational data.

   In addition to the stabilization time mentioned above, startups and switching from one boiler to the other required a significant amount of time to bring the boiler to operating temperature.

2. Equipment Issues – As noted in the timeline shown in Table 1 above, there were several instances of equipment malfunctions during the test period, and mandatory boiler inspections caused additional outages. The residue from the oversize shingle materials also caused one outage.

3. In early July while ramping up to 30% shingles, it was noted that emissions data were erratic. In order to insure that the emissions analyzers were functioning properly, the equipment was sent out for cleaning and calibration before testing was resumed.

In an effort to reduce the number of variables affecting results and conduct meaningful comparisons, Fayette Thermal's report includes only data from periods during which operations were deemed to be stable. Thus, over the five month test period there are three relatively brief sets of data available for analysis.

E. Ambient Relative Humidity Effects

During the test period, it became apparent that SO_2 and NO_x emissions tended to increase during periods of high ambient relative humidity (above about 65%). The limestone feed became inconsistent at this humidity. With the inconsistent feed, the distribution of limestone throughout the fluidized bed was not uniform, leading to decreased removal of SO_2 by the limestone. It is thought that this lack of uniformity also led to an inconsistent circulation of particles and lower heat transfer at a given temperature. With higher operating temperatures, NO_x emissions increased.

Boiler engineers also believe that there may be a thermodynamic phenomenon that occurs in these small boilers at high relative humidity, and this is under further study at this time.

Since relative humidity affected emission rates, a new baseline was established in September during a period of high humidity. While comparing data, it should be noted that tests during June and October were conducted at relative humidity less than 65%, while tests in September were conducted at relative humidity above 65%. As a result, data from TO+12 materials used in October should be compared to the June baseline, while the data from TO materials used in September should be compared to the September baseline.

Unfortunately, oxygen data for the September baseline test are not available. Therefore the emissions data for the baseline cannot be corrected for oxygen (excess air). Since no major changes were made in gas flow during this period, comparisons based on raw data (uncorrected) should be fairly indicative of the actual performance trend. In other words, the data are valid for demonstrating a decrease in emissions, but the magnitude of the change is subject to slight error.

IV. <u>Test Results</u>

A. Material Handling

In general, shingle materials that met the specifications shown in Exhibit A flowed well and did not present handling problems. However, some of the finer materials were prone to clumping if compacted or allowed to consolidate during storage or transport. Figures 4 and 5 show some of the clumped material.

The clumps were only problematic in the area of the feed hopper. Once the clumps reached the screw conveyor, they were readily crumbled by the mechanical action of the screw.

Clumpy TO Material In Stockpile
Figure 4

Clumpy TO Material At Feed Hopper
Figure 5

B. Effects on Boiler Operation

Boiler operators indicated that the boilers tended to be more stable using the shingle materials up to 40% due to the slower burning nature of the shingle materials compared to the coal materials. While no adverse effects on operations were noted at 40%, the boiler operators consider this to be the upper limit for these small boilers. Higher substitution rates may well be possible in larger boilers.

With the exception of the residue from the initial shingle materials containing oversize pieces, no issues concerning residue or boiler fouling were noted during the trial.

Measurement of the effects on boiler efficiency was beyond the scope of this trial, and the data are insufficient to reach any conclusions regarding efficiency. However, the boiler operator anticipates that the larger size distribution of the TO materials compared to the coal would reduce the moisture retention of the fuel mixture and therefore increase efficiency during wet weather conditions.

No differences in boiler operation were noted between the use of TO material and TO+12 material. Both materials behaved similarly in the boiler. Fayette Thermal personnel suggested that based on their experience using silica sand in the boilers for cleaning purposes, the TO material may lead to increased abrasion of the boiler internal surfaces over time.

C. Effects on Emissions

While the emissions data are somewhat clouded by uncertainties in feed ratios, issues with co-mingling of materials and the effects of changing relative humidity, it is clear that there is potential to reduce NO_x and SO_2 emissions in these boilers by using shingle materials. As shown in the summary section below, the use of shingle materials consistently led to lower NO_x and SO_2 emissions.

Note that emissions of SO_2 during the use of TO+12 material were not reduced as much as during the use of TO material. This is probably due to the fact that TO+12 material contains significantly less mineral content due to the absence of the granules. This higher proportion of organic material probably reduces scrubbing action and retention time. The increase in CO is probably indicative of a more fuel-rich mixture.

D. Effects on Limestone Use

Limestone used for control of SO_2 emissions is an expensive component of the boiler's cost of operation. Since the use of shingles tends to decrease SO_2 emissions as shown above, the potential exists to reduce limestone consumption. However, no testing was conducted during this trial to evaluate the effects of reducing limestone feed.

E. Effects on Ash Quality

The quantity of ash produced and the proportion of bottom ash to fly ash could not be measured during this testing. The combined ash was evaluated according to the SPLP (Synthetic Precipitation Leaching Procedure, ASTM Method 1312) criteria included in the facility's operating permit, and the ash continued to meet acceptable SPLP levels for constituents of concern throughout the test period. No adverse effects on ash quality were noted during the trial.

F. Summary

	25-Jun Low Humidity Baseline		27-Jun 20% TO Shingles		October 1 – 5 40% TO+12 Shingles		September High Humidity Baseline		Sept 19 - 24 40% TO Shingles	
	Raw	**@ 7% O_2**	**Raw**	**@ 7% O_2**	**Raw**	**@ 7% O_2**	**Raw**	**@ 7% O_2**	**Raw**	**@ 7% O_2**
CO (ppmv)	85	120	51	72	78	130	111	n/a	104	206
NO_x (ppmv)	274	385	264	375	228	377	288	n/a	268	528
SO_2 (ppmv)	118	165	84	119	91	150	117	n/a	83	163
CBT (^{o}F)	1631		1618		1614		n/a		1598	
Boiler Operation	Normal		Became unstable due to oversize		Increased Stability		Normal		Increased Stability	
Ash Quality	Acceptable		Acceptable		Acceptable		Acceptable		Acceptable	

Note: Shaded area indicates testing during high humidity conditions.

Table 3

Parameter	20% TO Shingles Compared to Low Humidity Baseline	40% TO Shingles* Compared to High Humidity Baseline	40% TO+12 Shingles Compared to Low Humidity Baseline
CO	Reduced 40%	Reduced 6.3%	Increased 8.3%
NO_x	Reduced 2.6%	Reduced 6.9%	Reduced 2.1%
SO_2	Reduced 27.9%	Reduced 29.1%	Reduced 9.1%

*Note: Values for 40% TO are based on raw data not corrected for O_2.

Table 4

V. Conclusions & Recommendations

A. **The use of chipped asphalt shingle materials from roof tear-offs in CFB boilers is technically feasible.** While this testing was insufficient to fully quantify the benefits and limitations of using these materials in CFB boilers, compatibility with the overall CFB process was clearly demonstrated. Shingle materials chipped to a top size of about 1 inch were well fluidized in the boiler fuel bed when used as up to 40% of the total fuel by weight. Acceptable combustion conditions were maintained, and ash quality also remained acceptable. No problems with residues or fouling were apparent.

B. **In some cases, boiler stability can be improved with the use of shingle materials as fuel.** The slower rate of combustion compared to coal allowed for increased residence time, lower bed temperature and greater heat transfer in these small CFB boilers.

C. **There is potential to reduce SO_2 and NO_x emissions using shingle materials as fuel.** Consistent reductions in SO_2 and NO_x emissions while using shingle materials were demonstrated.

D. **Both shingle materials with and without granules were stable in the CFB process.** These test results suggest that higher SO_2 and NO_x emissions reductions may be possible using materials including the granules, however more testing should be done to confirm this as stated below.

E. **Further testing is recommended to determine whether the use of shingle materials would allow a reduction in limestone consumption.** It may be feasible to reduce the amount of limestone required for SO_2 emissions control, particularly while using shingle materials that include granules.

F. **Longer term trials are recommended to optimize boiler operations, to evaluate the effects of shingle materials on long term boiler efficiency and to evaluate abrasion on boiler surfaces.**

G. **The optimal proportion of shingle fuel to normal fuel should be determined on a case-by-case basis.** While 40% shingles by weight appeared to be a maximum for these small boilers, there was no indication that this would be a limit for larger boilers, particularly if feeding mechanisms were more consistent and more easily controlled.

EXHIBIT A

SHINGLE MATERIAL SPECIFICATIONS

Revised 04/28/2008

TO Material Specifications

Parameter	Minimum Value	Maximum Value
Particle Size	NA	95% < 1 in
Longest edge length	NA	95% <1.25 in
Sulfur	NA	0.5%
Chlorine	NA	0.1%
Na + K	NA	5.0%
Heavy metals	NA	Cr <12ppm Hg <0.8ppm Mn <11ppm Ni <15ppm Pb <4.5ppm Zn <28ppm
Asbestos	NA	OSHA Hazard Communications Standard for Asbestos Employee Notification 29 CFR 1910.1200.D.4 <0.1% by weight of by volume, whichever is greater
Disturbing materials (nails, plastics, wood)	NA	1% by weight

TO+12 Material Specifications

Parameter	Minimum Value	Maximum Value
Particle Size	NA	95% < 3/8 in
Longest edge length	NA	95% <3/8 in
Sulfur	NA	0.5%
Chlorine	NA	0.1%
Na + K	NA	5.0%
Heavy metals	NA	Cr <12ppm Hg <0.8ppm Mn <11ppm Ni <15ppm Pb <4.5ppm Zn <28ppm
Asbestos	NA	OSHA Hazard Communications Standard for Asbestos Employee Notification 29 CFR 1910.1200.D.4 <0.1% by weight of by volume, whichever is greater
Disturbing materials (nails, plastics, wood)	NA	1% by weight

Appendix D

Recycled Shingles as Headlap Material Substitute in Roofing Shingles

MEMO REPORT

Science and Technology Center

Title: Recycled Shingle as Headlap Material Substitute in Roofing Shingles

Report number
06-T-137

Classification

Author(s)
Raj Nagarajan
Vivian Wong
Will Smith

Location

Date
12/08/2006

Project number

Signed

Countersigned

Laboratory notebook numbers

Abstract

The goal of this project was to explore and understand the use of recycled shingle tear-off as potential raw material substitutes in roofing. Any useful identification of reusing the roof tear-off in slip stream applications would help to reduce significant amounts of roof tear-off to be buried otherwise in landfills. The results of our feasibility study suggested that a blended mixture of 15% weight of -8/+20 mesh size fraction of shingle tear-off waste with 85% weight of standard coal slag headlap could be used as headlap substitute in shingles. Trials were conducted using pilot shinglet line as well as roofing plant locations. The physical and chemical characteristics of the -8/+20 size fractions were comparable to the current standard headlap (coal slag) used in shingle manufacturing. The shingle test specimens produced with the blended headlap revealed no significant differences in mechanical (tear or tensile strength) properties when compared to the shingles produced with the current standard headlap granules. In summary, the preliminary technical feasibility results are encouraging. Further refinement of the business case and large scale sieve separation capabilities of the roof tear-off have been identified as the necessary next steps.

keywords

Recycled shingle
Tear-off
Headlap
Granule
Coal slag
Filler
Asphalt
Granules
Tear
Tensile
Granule loss
Flow

distribution

Executive Summary

Project Objective

The objective of this study was to explore the potential use of recycled shingle tear-off waste as a shingle raw material substitute for headlap substitution.

Background

Currently about 11 million tons of recycled shingle tear-off is buried into landfill every year. Consistent with the corporate vision to support our sustainability efforts, a shingle recycling program was initiated to explore business opportunities to re-use the tear-off waste for (a) cement kilns as a fuel substitute and (b) other slip stream material substitution applications. The tear-off waste is comprised of both fuel-rich organic matters and mineral rich inorganic components. The present study was initiated as a part of "Alternate Materials and Technologies" exploration program that focused on exploring the use of mineral rich portion of the tear-off waste for headlap substitution in shingles. This project work would leverage the Department of Energy (DOE) grant received in 2006 for the "Shingle Recycling for Fuel" project and generate the sieved raw materials for slip stream applications. The shingle recycling program would be exploring business propositions for using appropriately sieved tear-off fractions for the desired end use applications based on the thermal, physical and chemical properties of the material.

Method

The recycled shingle tear-off materials from two recycling facilities were characterized for physical and chemical composition, flow characteristics and heat content. The incoming batches of shingle tear-off waste were screened for hazardous content using the EPA-600 protocol (particularly fibrous content) prior to use. Several sieve fractions of the shingle tear-off were identified for specific end use: +8 for fuel substitutes in cement kiln and CFB power plants, -8/+20 for headlap substitution, and -20/+50 and -50 mesh for filler substitution. A range of blended mixtures of sieved fractions of tear-off mixed with standard headlap granules was tested. A pilot scale shinglet trial was conducted. A small scale plant trial was later conducted at a roofing plant. The mechanical properties of the shinglet samples produced at the pilot line and the shingle specimens produced during a plant trial were tested for acceptability.

Results

Based on this study, we found that a blended mixture of 15% weight of -8/+20 mesh size fraction of recycled shingle with 85% weight of standard coal slag headlap could be used for headlap substitution in shingle products. The physical and chemical characteristics of the -8/+20 size fractions were comparable to the standard headlap (coal slag) used in shingle manufacturing. The flow properties and the particle size distribution of the blended granules were comparable to the standard headlap (coal slag) material. All shingle test specimens produced with the blended headlap revealed no significant differences in mechanical properties (tear or tensile strengths) compared to the shingles produced with standard headlap granules. Further refinement of the business case is required to determine if there are adequate amounts of this sieve fraction available with out any hazardous contamination at an affordable cost.

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Introduction

In the United States, nearly 11 million tons of shingle tear-off waste is removed every year and buried into landfills [1]. Consistent with OC's Corporate Sustainability vision, a program was initiated (led by Matt Zuschlag) to explore the business development opportunities around recycled shingles and help to reduce the amount of shingle tear-off that goes into landfills. The objectives of that program included exploring the business cases around recycling of shingles for environmentally friendly end uses. The business case exploration was done for (a) use of recycled shingle tear-off for cement kiln application as well as (b) other slip stream applications (e.g. raw material substitutes in shingles). The shingle composition consists of both organic and inorganic portions. The organic portion of the shingle may be more attractive for "fuel substitution" in cement kilns and circulating fluidized bed (CFB) for power plants, whereas the inorganic ingredients such as filler, granules, backdust, and mat may be more attractive for material substitution efforts. Tear-off waste typically consists of 80 – 90% asphalt based shingle, 0 – 10% wood, 5 – 13% tar paper, less than 1% metal and less than 1% other materials. A typical asphalt shingle (depending on manufacturer) is made up of 16 – 25% asphalt coating, 2 – 15% glass mat, 28 – 42% granules, 32 – 42% filler such as calcium carbonate and 3 – 6% backdust such as silica sand.

Shingle raw material productivity is a key issue for roofing plants due to lack of material availability and escalating cost of raw materials in recent years.

The combined amount spent on asphalt coating, prime granules and glass fiber mat makes up the majority of the cost and the combined spend on headlap, filler and sand make up the rest. Although the filler and headlap granules are relatively cheap, their timely availability and cost are the key drivers for exploring alternate materials for potential substitution.

A specific project was undertaken to explore the potential use of the shingle tear-off as headlap material substitute and the results of this study are summarized in this report. Our study suggested that a 15% weight of a selectively sieved fraction (-8/+20 or -12/+20) of the shingle tear-off could be blended with 85% standard headlap granules and could be used for producing shingles with out deteriorating shingle properties such as tear and tensile strengths.

Materials and Method

Shingle tear-off wastes were obtained from two recycling facilities. The incoming tear-off batches were screened for their hazardous materials content and only those that were cleared "free" of any asbestos-like fibrous material were used for the technical feasibility studies. The shingle tear-off was sieve separated using both lab-scale and commercial sieve separation equipment using outside resources. The physical properties such as density and flow characteristics were tested for various size fractions of the tear-off waste. The sieved material of the tear-off belonging to the -8/+20 size fraction was selected for the headlap substitution efforts after the preliminary screening. The sieve fractions at -20/+50 and -50 mesh were used for potential filler substitution.

The chemical characterization was carried out on the sieved fractions using X-ray fluorescence (XRF) and the results were compared with those obtained on standard headlap material (coal slag or crushed rocks as applicable). The heavy metal analysis was done using outside resources to determine the lead, mercury and other heavy metals present in the shingle tear-off. The technical feasibility studies on headlap substitution were conducted using two steps. The first step in the study was to conduct a pilot scale experiment using a shinglet line prototype facility. The second step in the feasibility study was conducted on production line at a roofing plant. The shinglets and the actual shingle samples produced were tested for product performance metrics such as tear and tensile strength. All product results were compared with the specimens prepared using standard headlap.

Results and Discussion

Shingle-Recycling Process Flow

A schematic of the overall shingle recycling material stream is shown in Fig 1. The process of shingle tear-off waste collection for the end use consists of the various steps shown in the flow chart. Typically, the incoming material is sorted, chipped, and sieved into various fractions to determine the end uses. The sieving results revealed that about 35% of the chipped recycled shingle was +8 size, 38% of was -8/+20, 17% -20/+50 size and 10% -50 mesh.

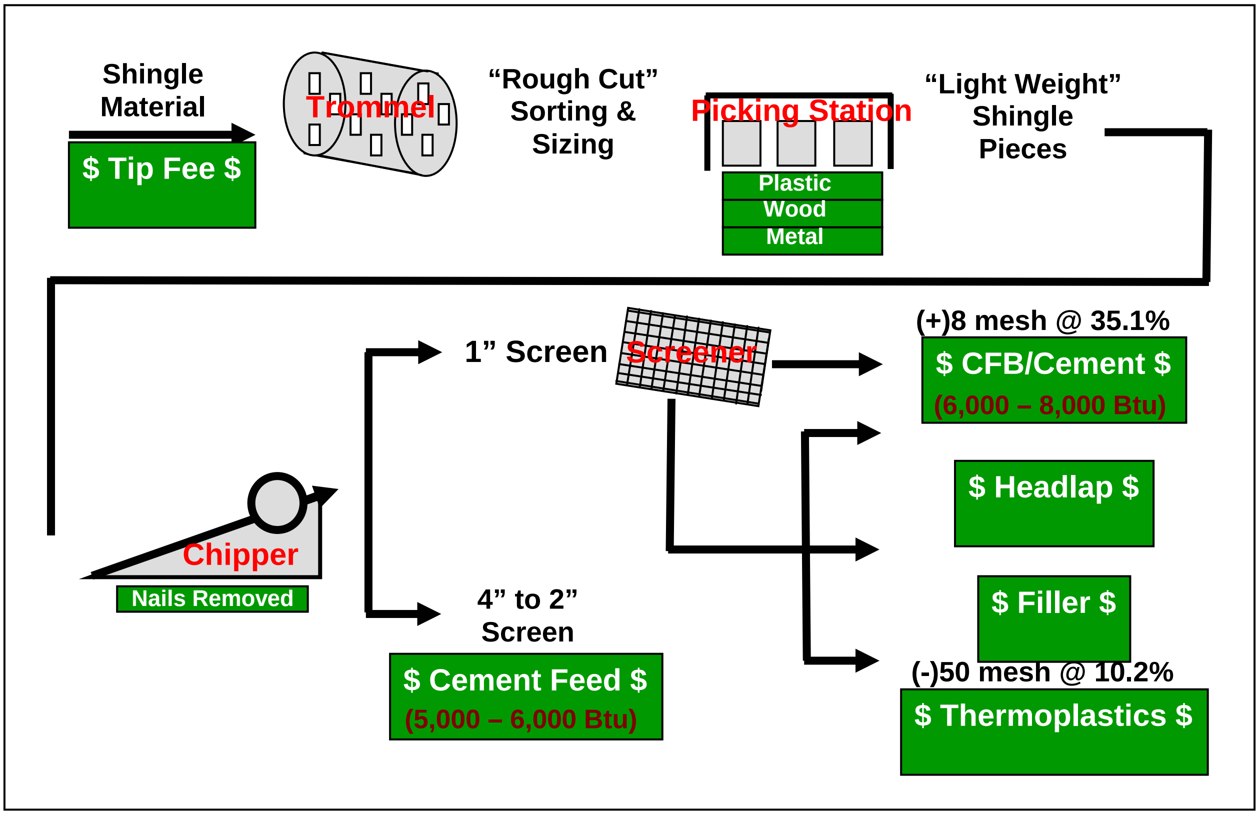

Fig. 1: Overview of shingle recycling process and potential opportunities.

Sieve results of -8/+20 size fraction

The -8/+20 sieved material was evaluated for the particle size distribution and the results shown in Table 1. It is evident that the particle size distribution of the -8/+20 fraction is comparable to the standard headlap (coal slag).

Test Values	**100% Recycled Shingle**
Sieve	Percentage
12	8.5
16	40.8
20	34.7
30	13.8
40	0.9
pan	1.3

Table 1: Sieve comparison for the -8/+20 mesh recycled shingle tear-off and coal slag headlap.

Flowability of Recycled Shingle

The preliminary flow characteristics revealed that the recycled tear-off selected for headlap substitution (-8/+20 mesh size) did not flow by itself. However, after it was blended with standard coal-slag headlap at the 10% or 15% level, the blended mixture demonstrated acceptable flow behavior as shown in Fig. 2.

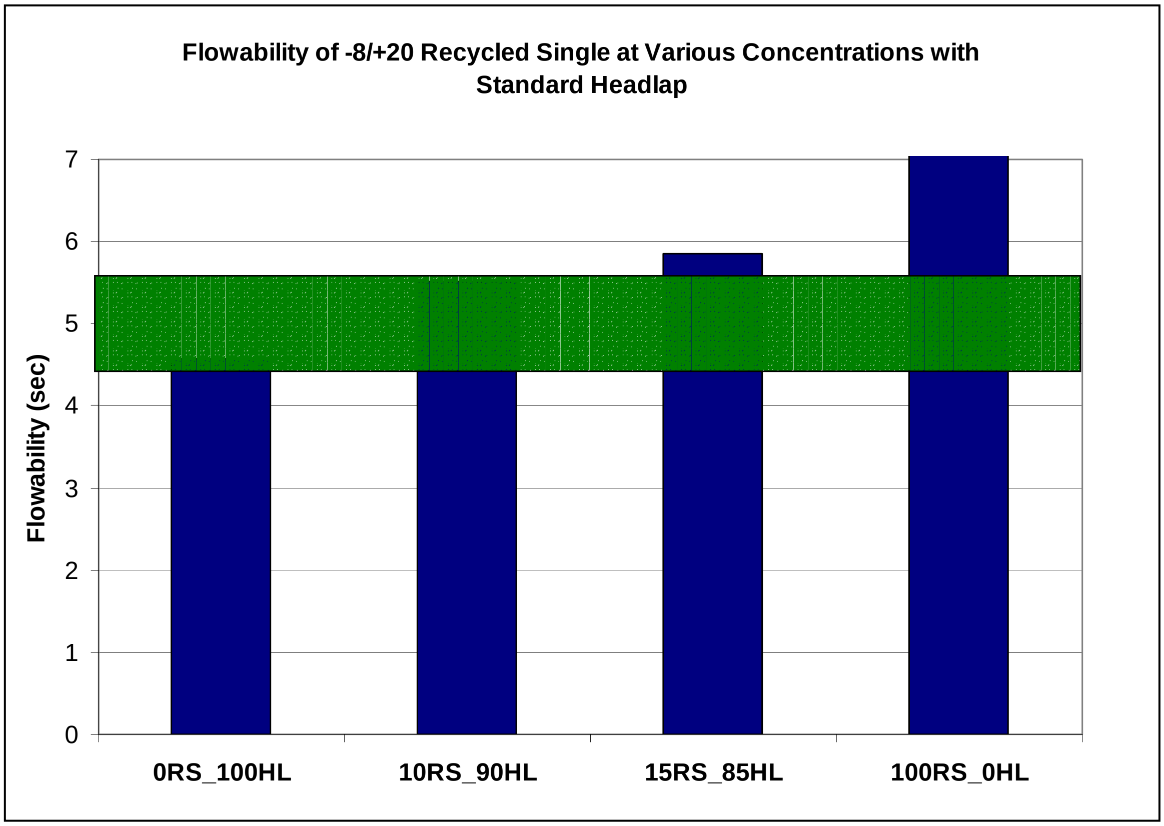

Fig. 2: Flowability of the blended mixture revealing the flow behavior. Example 0RS_100LH means 0% recycled shingle and 100% headlap granule was used. The green bar indicates passing flow in headlap material testing.

Shinglet Trial

A preliminary shinglet trial was conducted on a pilot line in which the blended headlap (i.e. 85% coal slag plus 15% mixture of -8/+20 RS) was applied onto glass mat coated with filled asphalt. The resulting 6-inch wide samples were used to prepare several test specimens for tear and tensile property testing. The tear and tensile test results on the shinglet are shown in Figs 3 and 4 respectively. There were no significant difference between the tear and tensile properties of the specimens. This suggested that the blended headlap could possibly be trialed (bucket trial) as an alternate headlap in a plant.

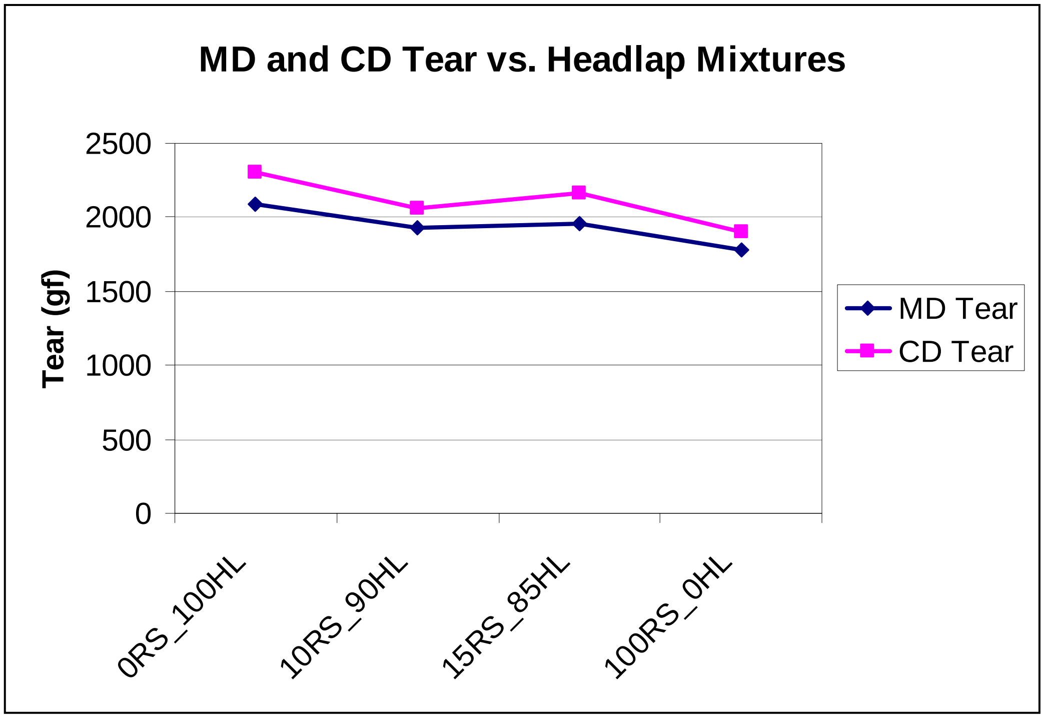

Fig. 3: Tear strength data obtained on the shinglet samples. Sample labels indicate % of recycled shingle and headlap blended for this study. Example 0RS_100LH means 0% recycled shingle and 100% headlap granule was used. MD and CD refer to the machine or cross-direction.

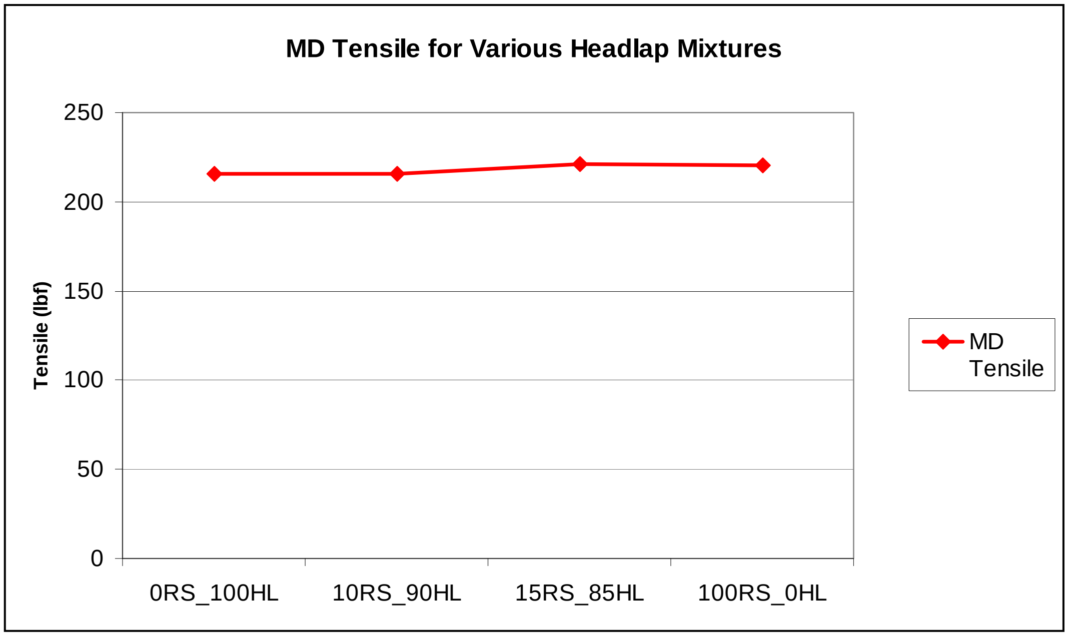

Fig. 4: Tensile strength data obtained on the shinglet samples. Sample labels indicate % of recycled shingle and headlap blended for this study. Example 0RS_100LH means 0% recycled shingle and 100% headlap granule was used.

Chemical Composition of Recycled Shingle

The next step was to understand the chemical compositions of the -8/+20 size fractions of the shingle tear-off and compare them with the standard headlap (coal slag). Table 2 shows the XRF data revealing that tear-off materials (-8/+20 mesh) are comparable to the coal slag composition. Now that it was confirmed that a blended composition could flow and has a similar chemistry to the coal slag, we proceeded with a plant trial using the blended headlap.

HL_Tear-off	Facility 1	Facility 2	Headlap	Estimated	Method
Sieve	-8 / +20	-8 / +20		Precision	
				(±1 sigma)	
SiO_2	53.6	54.1	45.2	±0.2	XRF
Fe_2O_3	8.9	7.6	9.2	±0.2	XRF
TiO_2	0.83	1.11	1.21	±0.05	XRF
Al_2O_3	15.6	15.3	20.6	±0.2	XRF
Cr_2O_3	0.04	0.04	0.03	±0.01	XRF
CaO	10.4	10.1	16.6	±0.2	XRF
SrO	0.02	0.02	0.25	±0.01	XRF
MgO	4.2	4.9	3.6	±0.1	XRF
K_2O	2.25	2.05	0.78	±0.05	XRF
Other Inorganic	4.24	4.76	2.64		

Table 2: Chemical composition of the -8/+20 size fraction of recycled shingle tear-off collected from recycling facilities.

Plant Trial (Bucket trial)

A 15% weight of -8/+20 mesh and -12/+20 mesh fractions of the tear-off material was blended separately with 85% weight coal slag headlap at the plant using a cement mixer. The blended samples were collected in 5-gallon buckets prior to the trial. The “bucket” samples were applied using the headlap applicator while the sheet was moving at a speed of about 400 fpm. There were no flow problems noticed during the plant trial and the sheet was uniformly covered. The shingle samples obtained from the trial were shipped to a test lab for further testing. The tear, tensile, and granule loss specimens were prepared and compared with shingles made using standard headlap during the trial. The shingle samples obtained during the trial are shown in Fig. 6.

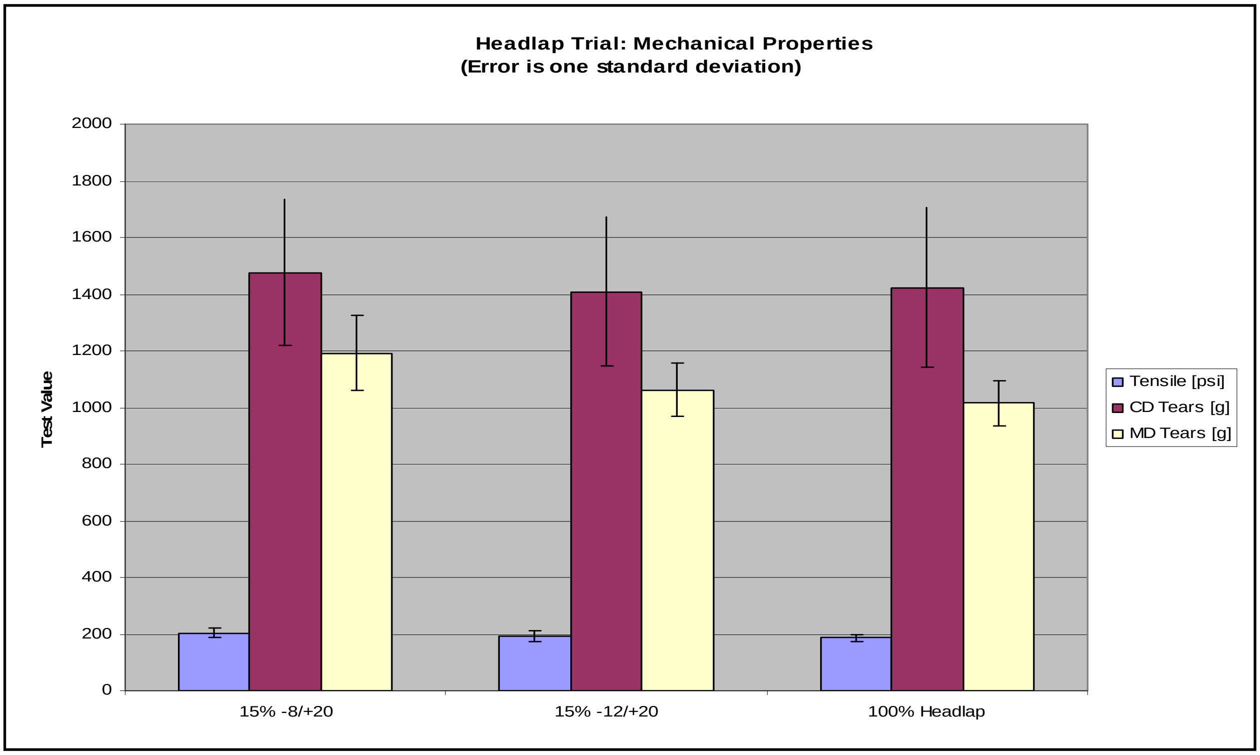

Fig. 5: Bar chart indicating the tear and tensile, cross-direction tear and machine-direction properties of 15%wt recycled shingle -8/+20 mesh size and -12/+20 mesh. Data obtained on shingles made with standard headlap is shown for comparison.

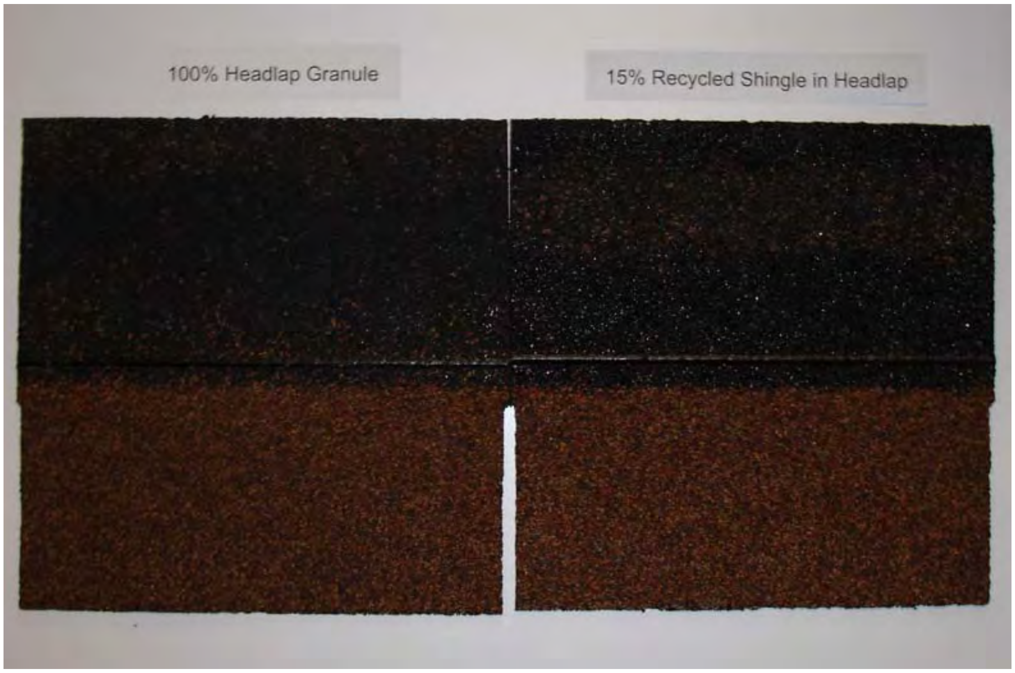

Fig. 6: Picture showing headlap portion of a shingle made with (a) standard headlap granule and (b) 15%wt recycled shingle -8/+20 mesh size.

It is evident from Fig. 6 that the blended headlap has a similar look as that of the standard headlap. The tear and tensile properties of the blended headlap (coal slag plus 15% mixture of either -8/+20 or -12/+20) did not reveal any significant difference with respect to the standard headlap. These results further confirms that a 15% wt of recycled shingle tear-off of either -8/+20 or -12/+20 size fractions mixed with 85% coal slag headlap could be used in shingle manufacturing. The fact that the headlap area of the shingle is not subjected to the stringent aesthetic scrutiny as that of the prime area (exposed area on the roof) provides added encouragement. However, it is suggested that long-term durability tests (e.g. algae resistance) on the headlap area may have to be conducted in future

Preliminary Risk Analysis

The team has identified several issues as potential risks at Stage-2 of this project as follows. This list would be updated and addressed during the next stages of this project.

1. Developing supplier relationship with shingle recycling facilities located within a fifty mile radius from the roofing plants may not be practical.
2. Substitution grade tear-off fractions (as per mesh size requirements) may not be cost-effective and may not be available in adequate quantities.
3. May be logistically challenging to trial some materials due to the proximity of the chipping location to the roofing plants.
4. May require significant process or product changes to utilize substitute materials (e.g. flow characteristics, temperature effects, mixing locations/techniques)
5. Increase in maintenance (reduced conversion efficiency) due to clogs in pipes and chutes in the short and/or long term. Further large scale testing and failure mode effects analysis would be conducted during the next stage of this project.
6. Lower than expected performance level after substitution in shingle products. Further large scale testing would help to address any identified issues, if any.
7. Lack of accepted industry long term shingle durability tests.

Summary and Conclusions

The preliminary studies reveal that a 15% wt of recycled shingle tear-off of either -8/+20 or -12/+20 size fractions mixed with 85% standard headlap could be used as alternate headlap source in shingle manufacturing.

Appendix-1: Sieve Size

(Reference: http://www.azom.com/details.asp?ArticleID=1417)

Two scales that are used to classify particle sizes are the US Sieve Series and Tyler Equivalent, sometimes called Tyler Mesh Size or Tyler Standard Sieve Series. The most common mesh opening sizes for these scales are given in the table below and provide an indication of particle sizes.

USU Sieve Size	Tyler Equivalent	Opening	
		mm	in
-	2½ Mesh	8.00	0.312
-	3 Mesh	6.73	0.265
No. 3½	3½ Mesh	5.66	0.233
No. 4	4 Mesh	4.76	0.187
No. 5	5 Mesh	4.00	0.157
No. 6	6 Mesh	3.36	0.132
No. 7	7 Mesh	2.83	0.111
No. 8	8 Mesh	2.38	0.0937
No.10	9 Mesh	2.00	0.0787
No. 12	10 Mesh	1.68	0.0661
No. 14	12 Mesh	1.41	0.0555
No. 16	14 Mesh	1.19	0.0469
No. 18	16 Mesh	1.00	0.0394
No. 20	20 Mesh	0.841	0.0331
No. 25	24 Mesh	0.707	0.0278
No. 30	28 Mesh	0.595	0.0234
No. 35	32 Mesh	0.500	0.0197
No. 40	35 Mesh	0.420	0.0165
No. 45	42 Mesh	0.354	0.0139
No. 50	48 Mesh	0.297	0.0117
No. 60	60 Mesh	0.250	0.0098
No. 70	65 Mesh	0.210	0.0083
No. 80	80 Mesh	0.177	0.0070
No.100	100 Mesh	0.149	0.0059
No. 120	115 Mesh	0.125	0.0049
No. 140	150 Mesh	0.105	0.0041
No. 170	170 Mesh	0.088	0.0035
No. 200	200 Mesh	0.074	0.0029
No. 230	250 Mesh	0.063	0.0025
No. 270	270 Mesh	0.053	0.0021
No. 325	325 Mesh	0.044	0.0017
No. 400	400 Mesh	0.037	0.0015

The mesh number system is a measure of how many openings there are per linear inch in a screen. Sizes vary by a factor of √2. This can easily be determined as screens are made from wires of standard diameters, however, opening sizes can vary slightly due to wear and distortion.

US sieve sizes differ from Tyler Screen sizes in that they are arbitrary numbers.

Primary author: AZoM.com

Appendix E

Recycled Shingle as Headlap Material Substitute in Roofing Shingles: Truckload Trial

Science and Technology Center

MEMO REPORT

title

Recycled Shingle as Headlap Material Substitute in Roofing Shingles: Truckload Trial

report number
07-M-79

classification
II

author(s)
Will Smith
Raj Nagarajan

location

date
September 14, 2007

project number

signed
Will Smith

countersigned

laboratory notebook numbers
6984

abstract

The goal of this project was to build upon small scale trials that showed promising results in using recycled shingle as material substitute for headlap granules. Using a blended headlap composed of 15% ground and screened recycled shingle (-12/+20 mesh) and 85% current headlap granules, a trial was conducted at a roofing plant. Two truckloads of the blended headlap showed no deterioration in shingle properties as measured by end-of-line scrubs, visual inspection, and mechanical property testing in a test lab. The trial did show a processing issue involving the lightweight fibers and organic material that remains in the recycled shingle after it has been screened. Removal of this lightweight material will improve the material handling and potentially lead to a higher % of recycled shingle to be blended into the headlap. There is additional value of creating alternative sources of headlap that can be used to replace the dwindling supply of headlap materials, i.e. coal slag.

keywords

Recycled shingle
Tear-off
Sustainability
Headlap
Granule
Coal slag
Asphalt
Scrub
Shingle
Manufacturing
Tear
Tensile
Granule loss
Flow

distribution

Executive Summary

Project Objective

The objective of this study was to explore the scale-up of using recycled shingle tear-off waste as a headlap substitute in roofing shingles.

Background

Previous work involved laboratory measurements, a shinglet pilot scale trial, and a bucket trial of a blended headlap at a roofing plant. The work was part of a larger project consistent with the sustainability vision initiated to explore business opportunities to re-use roof tear-offs and post-industrial shingle waste as a fuel source and as a raw material substitute in the shingles.

Method

The recycled shingle tear-off was collected and processed at an offsite recycling facility. The incoming batches of shingle tear-off waste were screened for hazardous content using EPA protocol (particularly fibrous content) prior to use. The shingle tear-off was ground and then screened. The -12/+20 mesh fraction of the screened material was then mixed at a 15 wt % with black roofing granules. Two truckloads of the blended headlap were processed on two separate days at a roofing plant. Testing on the produced material was completed both on end-of-line samples and samples shipped back to the lab.

Results

The present study confirmed that a blended mixture of 15% weight of -12/+20 mesh size fraction of recycled shingle with 85% weight of standard headlap could be used for headlap substitution in shingle products. Both the end-of-line tests, visual inspection, and testing showed results that were consistent with the OC commitment to quality. The trial did verify that the lightweight material in the recycled shingle hinders the processing of the blended headlap at the roofing plant. The residual fibers and organic material present in the screened recycled shingle material clogged screens at the roofing plant inhibiting flow of the blended headlap. Additional steps are necessary in the processing of the recycled shingle, such as air separation, to remove the lightweight material if the blended headlap is going to be used in the current manufacturing plants.

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Introduction

The work was part of a larger project consistent with the sustainability vision initiated to explore business opportunities to re-use roof tear-offs as a fuel source and as a raw material substitute in the shingles. Previous work involved laboratory measurements, a shinglet pilot scale trial, and a bucket trial of a blended headlap at the roofing plant. Building upon the encouraging results of the earlier work, a two truckload trial of blended recycled shingle was completed at the roofing plant. The trial also involved the investigation of large scale screening and blending equipment to process the ground up recycled shingle into its final form.

Materials and Method

The recycled shingle tear-off was collected and processed at an offsite recycling facility. The material was screened for hazardous materials. The shingle tear-off was chipped and then screened. The screening equipment used in the trial was rented from Sweco. Capability testing was completed to demonstrate the ability of the equipment to adequately separate the material. The -12/+20 mesh fraction of the screen material was then mixed at a 15 wt % with black roofing granules from the quarry. Forty tons of granules were shipped in supersacks to the recycling facility. The final headlap product was blended using a 10 cubic foot Roll-O-Mixer Model VII 31-10/90s manufactured by Continental Products, Inc. Three minutes of mixing was used to blend the standard granules and recycled shingle. The blending capability was tested prior to the blending at the recycling facility. The capability testing was held at Continental's facility using the exact mixer used at the recycling facility to adequately blend the two granules.

The entire processing of the recycled shingle, including the screening and blending, was completed at the recycling facility. The two truckloads of blended headlap that were produced were then used on two separate days at the roofing plant on the strip line. The first truckload was run on 6/14/07 and the second truckload on 6/28/07. Samples of the raw material were collected during the unloading of the material and characterized before the blended headlap was used in the plant. During the trial, visual observations were used along with end-of-line granule loss (scrub) measurements on both the headlap and prime sections to make a preliminary judgment on the quality of the shingles. Trial samples were collected from lanes 1 and 3 every thirty minutes, along with a control sample before and after the trial. The control for the first truckload trial was standard granules. The control for the second truckload was coal slag. Further testing was completed on samples shipped to the testing lab, which included wet and dry scrubs, tear and tensile test from the headlap, sticking in the headlap, and chemical composition. Five pallets of material from the first truckload of blended headlap were placed outside at the facility to investigate sticking within the bundle. The pallets were stacked 2 high and 3 high.

Results and Discussion

Raw Material Characterization

The blended recycled shingle headlap was characterized at three different times. Before the blending occurred at the recycling facility, a sample of the -12/+20 recycled shingle was sent to the testing lab and mixed with standard granules. Samples from each of the truckloads were also collected and tested. The results of these three characterizations are shown in Table 1, along with the current specifications for headlap material. These results verify that the material meets the current specifications and is consistent between the two truckloads. It is noted that the flowability is at the upper spec limit for the two truckloads and was actually higher than the spec limit for the sample tested in the lab.

Table 1: Raw material characterization of 15% recycled shingle (-12/+20) blended with 85% standard granules.

Testing Location				**Specification**	
Material	**Pre-Trial**	**Truckload 1**	**Truckload 2**	**Min**	**Max**
Sieve Analysis Sieve	% Retained				
8	0.0	0.0	0.0	0	1
12	5.0	7.2	8.2	2	13
16	37.7	39.6	41.9	30	45
20	34.6	31.3	29.7	25	35
30	17.9	18.5	16.8	12	22
40	4.5	2.9	2.7	3	10
Pan	0.3	0.4	0.7	0	3
Bulk Density [lbs/cubic ft]	87.4	90.8	93.1	87.1	92.4
Flowability [sec]	5.7	5.5	5.4	5.0	5.5
Moisture [%]	0.17			0	0.3
Rust (# of spots)	2 (may be due to asphalt and not rust)			0	5

Shingle Testing Results

End-of-line Testing

Visual inspection of the trial material was used to verify no aesthetic issues, and scrub measurements were used to test for granule adhesion. No visual defects were seen for either of the two truckloads of blended recycled shingle headlap. End-of-line scrub testing on the produced shingles using the 15% recycled shingle blended headlap was limited to the first truckload due to resource constraints during the second truckload trial. Results in Table 2 show that there is no significant difference between the control and the trial samples for the first truckload. Scrub data was taken on both the headlap and the prime sections of the shingle.

Table 2: End-of-line scrub data from the first truckload trial, including a control.

Control Sample		Control Sample		Trial Material		Trial Material	
Headlap		Prime		Headlap		Prime	
Time	10:15	**Time**	10:15	**Time**	11:15	**Time**	11:15
Product	Supreme	**Product**	Supreme	**Product**	Supreme	**Product**	Supreme
Color	Surf Green	**Color**	Surf Green	**Color**	Surf Green	**Color**	Surf Green
Press	46.5/46.5	**Press**	46.5/46.5	**Press**	46.5/46.5	**Press**	46.5/46.5
Avg.	0.226	**Avg.**	0.186	**Avg.**	0.108	**Avg.**	0.113
Range	0.3	**Range**	0.12	**Range**	0.07	**Range**	0.14
Lane 4		**Lane 4**		**Lane 4**		**Lane 4**	
0.27	0.34	0.23	0.24	0.14	0.11	0.26	0.20
0.37		0.24		0.09		0.2	
0.38		0.25		0.09		0.14	
Lane 3		**Lane 3**		**Lane 3**		**Lane 3**	
0.12	0.08	0.12	0.12	0.07	0.08	0.06	0.07
0.07		0.17		0.1		0.08	
0.05		0.07		0.07		0.07	
Lane 2		**Lane 2**		**Lane 2**		**Lane 2**	
0.1	0.10	0.08	0.18	0.11	0.10	0.05	0.06
0.12		0.23		0.09		0.05	
0.08		0.24		0.09		0.09	
Lane 1		**Lane 1**		**Lane 1**		**Lane 1**	
0.57	0.38	0.21	0.20	0.14	0.15	0.11	0.12
0.37		0.23		0.18		0.14	
0.21		0.16		0.13		0.1	

Trial Material		Trial Material		Trial Material		Trial Material	
Headlap		Prime		Headlap		Prime	
Time	12:15	**Time**	12:15	**Time**	13:15	**Time**	13:15
Product	Supreme	**Product**	Supreme	**Product**	Supreme	**Product**	Supreme
Color	Surf Green	**Color**	Surf Green	**Color**	Surf Green	**Color**	Surf Green
Press	41/42.5	**Press**	41/42.5	**Press**	38.5/38.5	**Press**	38.5/38.5
Avg.	0.124	**Avg.**	0.219	**Avg.**	0.188	**Avg.**	0.222
Range	0.17	**Range**	0.18	**Range**	0.16	**Range**	0.13
Lane 4		**Lane 4**		**Lane 4**		**Lane 4**	
0.16	0.11	0.12	0.15	0.37	0.25	0.21	0.22
0.09		0.17		0.17		0.25	
0.09		0.15		0.22		0.21	
Lane 3		**Lane 3**		**Lane 3**		**Lane 3**	
0.07	0.07	0.15	0.15	0.12	0.09	0.15	0.17
0.08		0.15		0.1		0.16	
0.06		0.15		0.06		0.21	
Lane 2		**Lane 2**		**Lane 2**		**Lane 2**	
0.07	0.07	0.13	0.25	0.15	0.10	0.14	0.31
0.1		0.19		0.1		0.42	
0.04		0.44		0.06		0.36	
Lane 1		**Lane 1**		**Lane 1**		**Lane 1**	
0.14	0.24	0.34	0.33	0.27	0.30	0.25	0.18
0.29		0.28		0.39		0.19	
0.3		0.36		0.24		0.11	

Testing in Test Lab

The trial samples collected for both truckloads were tested in the test lab. The results of the shingle properties, displayed in Table 3 and Table 4, show that there is no significant variation between the trial materials with the recycled shingle blended headlap and the control.

Table 3: Testing results from first truckload produced on 6/14/07.

Sample	Lane	Headlap Tears [grams]			
		MD Avg	MD SD	CD Avg	CD SD
Control Beginning	1	1274.2	131.4	1650.6	219.6
Trial Material 1	1	1281.6	114.5	1872.0	291.4
Trial Material 3	1	1273.9	96.8	1868.8	282.1
		Headlap Tensile [lbs]			
		MD Avg	MD SD	CD Avg	CD SD
Control Beginning	1	196.5	13.2	117.1	8.4
Trial Material 1	1	194.3	13.5	109.4	7.5
Trial Material 3	1	214.3	19.4	107.4	9.4
		Scrubs (Dry)			
		HL Avg	HL SD	Prime Avg	Prime SD
Control Beginning	1	0.22	0.05	0.17	0.07
Trial Material 1	1	0.14	0.03	0.08	0.01
Trial Material 3	1	0.31	0.15	0.22	0.03
		Scrubs (Wet)			
		HL Avg	HL SD	Prime Avg	Prime SD
Control Beginning	1	0.72	0.13	0.57	0.15
Trial Material 1	1	0.42	0.05	0.34	0.03
Trial Material 3	1	0.93	0.26	0.93	0.20
		Square Weight [lbs]	Thickness [in]	Sticking [lbs] *	
			HL	FB Avg	FB SD
Control Beginning	1	224	0.108	72.4	14.6
	3	228	0.114	54.9	16.0
Trial Material 1	1	234	0.111	99.6	19.8
	3	233	0.115		
Trial Material 2	1	234	0.119		
	3	239	0.119	57.0	15.0
Trial Material 3	1	225	0.120	88.4	7.3
	3	233	0.114		
Control End	1	230	0.114		
	3	233	0.114		
Control Average		228.60			
Trial Average		233.05			

* Sticking test was made on the headlap samples using 10 lbs of weight

Table 4: Testing results from the second truckload produced on 6/28/07.

Sample	Lane	Headlap Tears [grams]			
		MD Avg	MD SD	CD Avg	CD SD
Control Beginning	1	1228.8	136.2	1302.7	180.7
Trial Material 1	1	1267.8	66.0	1721.6	413.8
Trial Material 3	1	1266.9	138.8	1671.4	341.3
		Headlap Tensile [lbs]			
		MD Avg	MD SD	CD Avg	CD SD
Control Beginning	1	182.4	11.2	99.8	6.5
Trial Material 1	1	193.2	15.4	125.1	9.8
Trial Material 3	1	206.2	12.2	113.4	8.8
		Scrubs (Dry)		Scrubs (Wet)	
		HL Avg	HL SD	HL Avg	HL SD
Control Beginning	1	0.26	0.16	0.95	0.25
Trial Material 1	1	0.24	0.07	0.88	0.15
Trial Material 3	1	0.34	0.12	1.40	0.17
Sample	Lane	Square Weight [lbs]			
Control Beginning	1	212			
	3	228			
Trial Material 1	1	219			
	3	233			
Trial Material 2	1	216			
	3	225			
Trial Material 3	1	220			
	3	228			
Trial Material 4	1	216			
	3	225			
Control End	1	220			
	3	231			
Control Average		222.72			
Trial Average		222.65			

Additional testing was made through compositional analysis of the sample for the two truckloads along with the controls. There were no substantial changes in shingle composition.

Sticking Results

After eight weeks of storage outside at the facility, with temperatures surpassing 90 F during that time, bundles were inspected for any sticking. The product was from the first truckload, and the pallets were stacked three high. The inspection of the bundles by the quality team at the plant from different places within the stack showed no evidence of sticking of the shingles within the bundle.

Summary

The results from running two truckloads of 15 % recycled shingle blended headlap at the plant showed promising results. The evaluation of the final product showed no quality issues when compared to controls from the plant. The testing included end-of-line scrub and visual inspection, sticking in the bundle, tear strength, tensile strength, and compositional analysis. This was in agreement with the findings with raw material analysis where there was essentially no differences between the 15 % recycled shingle blended headlap and the headlap currently used at the plant. The results of this trial confirm the positive results of the previous bucket trial.

The trial highlighted the supplier requirements in processing the material, including evaluation of large scale mixing and screening equipment. The trial clearly demonstrated the essential need of removal of the lightweight materials from the recycled shingle stream, such as with an air knife or air classifier. The presence of the lightweight material inhibits the flow properties of the headlap in a way unacceptable for the manufacturing process.

As a part of the next steps, it is recommended that Owens Corning must continue exploration efforts to use post-industrial recycled shingles in shingle manufacturing. It is further recommended that Owens Corning must develop a “supplier” relationship with the recyclers and provide raw material specifications to ensure that the recycled materials will meet all Owens Corning product stewardship guidelines.

Appendix F

Recycled Shingle as Filler and Asphalt Substitute in Roofing Shingles

Science and Technology Center

MEMO REPORT

title

Recycled Shingle as Filler and Asphalt Substitute in Roofing Shingles

report number
07-M-78

classification
II

author(s)
Will Smith
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location

date
July 31, 2007

project number

signed
Will Smith
Donn Vermilion
Raj Nagarajan

Countersigned
Gerry Greaves

laboratory notebook numbers
6984

abstract

The goal of this project was to explore and understand the use of recycled shingle tear-off as potential filler and asphalt substitutes in roofing. Any identification of using roof tear-off would help reduce significant amounts of roof tear-off to be buried otherwise in landfills. Similarly, if the asphalt content from the recycled shingle can be used as an asphalt substitute, there would be less reliance on the dwindling supply of roofer's flux. The results of the feasibility study suggest that a -20 mesh size fraction of shingle tear-off waste would have the greatest impact as both filler and asphalt substitute. Trials were conducted using the pilot shinglet line. The physical and chemical characteristics of the -20 size fractions were compared to samples prepared with virgin material. The shingle test specimens produced with the recycled shingle filler revealed no significant differences in mechanical (tear or tensile strength) properties compared to shingles produced with the current filled coating. There is an issue to the presence of asphalt with the filler in that it would require process development and additional material handling equipment. In summary, the preliminary technical feasibility results are encouraging, as are potential cost savings but process development and capital would be required for material handling equipment in order to implement. Further refinement of the business case is essential, and if the business case warrants, plant trials have been identified as the necessary next steps.

keywords

Recycled shingle
Tear-off
Filler
Calcium Carbonate
Asphalt
Tear
Tensile
Flow
Recycled
Reclaimed asphalt
Weathering
Shinglet
Material substitute

distribution

*executive summary only

Executive Summary

Project Objective

The objective of this study was to explore the potential use of recycled shingle tear-off waste as a shingle raw material substitute for mineral filler and asphalt.

Background

Currently about 11 million tons of recycled shingle tear-off are buried in landfills every year. Consistent with the corporate vision to support sustainability efforts, a shingle recycling program was initiated to explore business opportunities to re-use the tear-off waste as (a) fuel substitute and (b) other slip stream material substitution applications. The tear-off waste is comprised of both fuel-rich organic matters and mineral rich inorganic components. The present study was initiated as a part of "Alternate Materials and Technologies" exploration program that focused on exploring the use of the tear-off waste for filler and asphalt substitution in shingles. This project work would leverage the Department of Energy (DOE) grant received in 2006 for the "Shingle Recycling for Fuel" project and generate the sieved raw materials for additional applications. The shingle recycling program would be exploring business propositions for using appropriately sieved tear-off fractions for the desired end use applications based on the thermal, physical, and chemical properties of the material.

Method

The recycled shingle tear-off from two recycling facilities were characterized for physical and chemical composition. The incoming batches of shingle tear-off waste were screened for hazardous content using EPA protocol (particularly fibrous content) prior to use. The sieve fraction of -20 mesh was identified for filler substitution. A range of blended mixture of sieved fractions of tear-off mixed with standard limestone filler was tested. A pilot scale shinglet trial was conducted, and the mechanical properties of the shinglet samples were tested for acceptability and the filled coating was tested for weathering.

Results

Shinglet testing was completed up to a 20% level of substitution of the recycled shingle. The preliminary studies reveal that there is an opportunity to use a -20 mesh ground recycled shingle as a raw material substitute for limestone filler and asphalt. There is a significant financial incentive to be able to use the asphalt from the recycled shingle to displace virgin asphalt compared to only using the recycled shingle as a filler substitute. While the material substitution shows financial promise, there are technical and sourcing hurdles to overcome to implement this at a roofing plant. Further testing is essential, especially on a plant processing line, to validate the preliminary results.

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Introduction

In conjunction with other projects investigating the use of shingle tear-off as fuel source for cement kilns and circulating fluidized bed power plants, investigation was initiated in exploring the use of shingle tear-off as a raw material substitute in roofing shingles, including headlap granules. A specific project was undertaken exploring the use of the shingle tear-off as a mineral filler and asphalt material substitute, and the results of this study are summarized in this report.

Literature and patent reports revealed that others have investigated the use of recycled shingles in related applications. A novelty search was conducted related to IR 25758, which is on file in the IP Group. Additionally, a sub-team from Owens Corning explored the interest of using recycled shingles as a filler substitute with one of our current filler suppliers.

Due to the high cost of raw materials, there are clear financial incentives to find alternative materials that are less costly due to the magnitude of raw materials that are consumed in roofing shingle manufacturing.

Materials and Method

Shingle tear-off wastes were obtained from two recycling facilities. The incoming tear-off batches were screened for their hazardous materials content and only those that were cleared “free” of any asbestos-like fibrous material were used for the technical feasibility studies. The chemical characterization was carried out on the sieved fractions using X-ray fluorescence (XRF) and the results were compared with those obtained on standard shingle raw materials. The bulk material physical properties were also investigated, such as density and flowability.

Investigation into the impact on the shingle performance from using the recycled shingle as a raw material was completed on the shinglet line. The shinglet samples were conditioned for one week before testing tensile and tear strength. Further studies were undertaken on the filled coating at the Asphalt Technology Laboratory, including weatherometer and viscosity tests. All results were compared with the specimens prepared using standard raw materials.

Results and Discussion

Chemical Composition

Tables 1 and 2 display the chemical compositions of samples of recycled shingles from both recycling facilities from report 85072. The XRF analysis included heating the material to remove any organics, including asphalt. Thus, the values in the Table 1 represent the composition of the inorganic components in the material. The % $CaCO_3$ and % $MgCO_3$ are calculated from CaO and MgO values due to loss of CO_2 upon heating. The % asphalt in Table 2 was determined through chemical extraction of the asphalt. Comparison to current raw materials included the coal slag headlap and mineral filler. The results indicate that the sieve that most closely matches the chemical composition of the current filler would be from the -50 mesh, as this fraction has the highest level of $CaCO_3$ and the lowest level of $MgCO_3$ and SiO_2. At the pure level, the recycled shingle sieve fractions of -20/+50 and -50 do not meet the minimum levels of $CaCO_3$ (90%) or maximum levels of SiO_2 (1.5%). Previous work and experience has shown that high levels of sand and hard fillers can negatively impact shingle performance, while high levels of $CaCO_3$ are desirable.

Table 1: Inorganic composition comparison of the recycled shingle sieve fraction and current raw materials from XRF analysis.

	Facility 1			Facility 2		
	-8 / +20	-20 / +50	-50	-8 / +20	-20 / +50	-50
SiO_2	**53.6**	**46.9**	**31.7**	**54.1**	**46.9**	**38.2**
Fe_2O_3	8.9	6.9	4.7	7.6	6.8	4.4
TiO_2	0.8	0.7	0.5	1.1	0.9	0.6
Al_2O_3	15.6	12.6	6.3	15.3	12.7	8.6
Cr_2O_3	0.04	0.04	0.05	0.04	0.06	0.04
CaO	10.4	20.2	38.2	10.1	17.2	28.4
SrO	0.02	0.02	0.02	0.02	0.02	0.02
MgO	4.2	5.8	10.8	4.9	8.3	13.4
K_2O	2.2	1.9	0.9	2.0	1.7	1.2
$CaCO_3$	**19**	**36**	**68**	**18**	**31**	**51**
$MgCO_3$	**9**	**12**	**23**	**10**	**17**	**28**

Table 2: Asphalt levels of the different sieve fractions of recycled shingle tear-offs.

	Facility 1			Facility 2		
	-8 / +20	-20 / +50	-50	-8 / +20	-20 / +50	-50
Asphalt	16	26	-	18	24	36

Flowability of Recycled Shingle for Filler Substitution

Room Temperature

Using the current test method for evaluating filler flowability (ESB G-33.0), the different sieve fractions of recycled shingle from Facility 2 were measured both in the pure state and also mixed with limestone filler (LF). The results in Fig. 1 show that at the testing temperature of 70 F the -20/+50 mesh fraction flows as well as the limestone filler. Additionally, the addition of just 1% of filler to the -50 mesh fraction greatly increases the flowability to above the minimum specification of 90%.

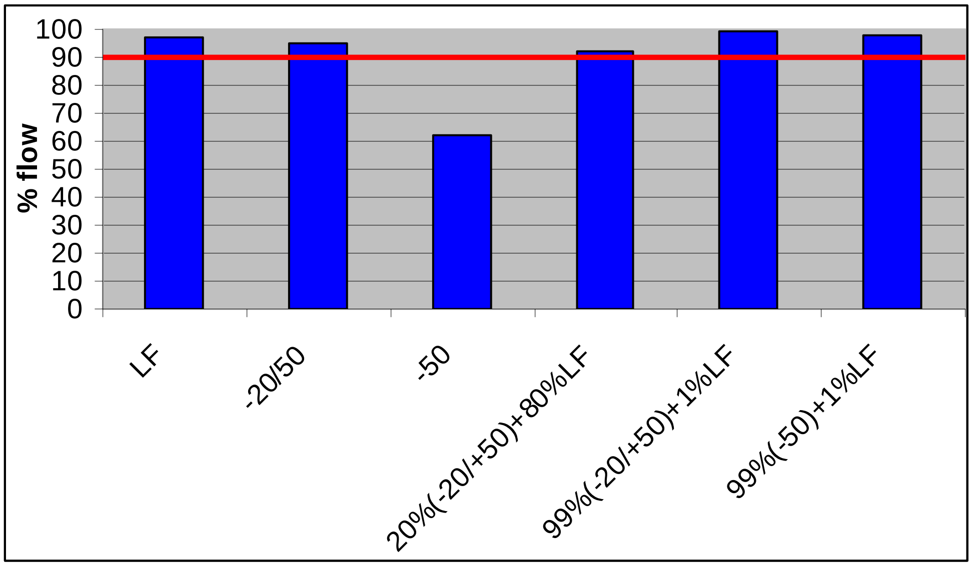


Fig. 1: Flowability of recycle shingle mesh fractions. The red line indicates the minimum specification of 90% flow.

Elevated Temperatures

Due to the presence of asphalt in the recycled shingle, there was concern about the material handling at elevated temperatures above 70 F that could occur during processing and transportation of the material. Samples of -20/+50 mesh fractions were heated to 149 F and then immediately taken from the oven to be tested. Samples were also prepared with 2, 5 and 10% limestone filler as well. When attempted to pour into the volumeter, only the -20/+50 + 10% LF poured out of the container. The other samples either stuck to the side or came out in one clump. This clearly demonstrated the necessity of an anti-blocking agent, such as the limestone filler during the material transport of the recycled shingle once it is ground into a powder. A simple qualitative study of putting the material in a glass jar in the oven showed that the pure -20/+50 and -50 mesh fractions clumped together at temperatures less than 105 F, while -20/+50 mixed with 15% limestone filler will at least pour out of a container at temperatures greater than 210 F.

Weathering

Samples of the facility 2 recycled shingle -50 mesh fraction were tested in a weatherometer. Samples were mixed with limestone filler and coating asphalt. The samples remained in the chamber until failure or a maximum of 150 cycles. All the filled coating samples did not fail before 150 cycles. These results indicate that there were no adverse effects detectable by this accelerated weathering up to 20% substitution of -50 mesh recycled shingle for limestone filler.

Shinglet Trials

Filler Substitution: Shinglet Trial #1

Shinglet trials were conducted on a pilot line in which a 6-inch wide strip was tested for mechanical performance. The initial trial used a -20 mesh fraction of recycled shingle from Facility 2 mixed with limestone filler and coating asphalt from a plant. Controls were made with 65% limestone filler. Two samples were made with filled coating using the -20 mesh recycled shingle. The first contained 35% asphalt, 55% limestone filler, and 10% -20 mesh recycled shingle. The second contained 35% asphalt, 45% limestone filler, and 20% -20 mesh recycled shingle. The results of the tensile and tear tests shown in Fig. 2 exhibit no deterioration in mechanical performance from the filler substitution of the recycled shingle produced on the shinglet line. (Note the log scale on Fig. 2.)

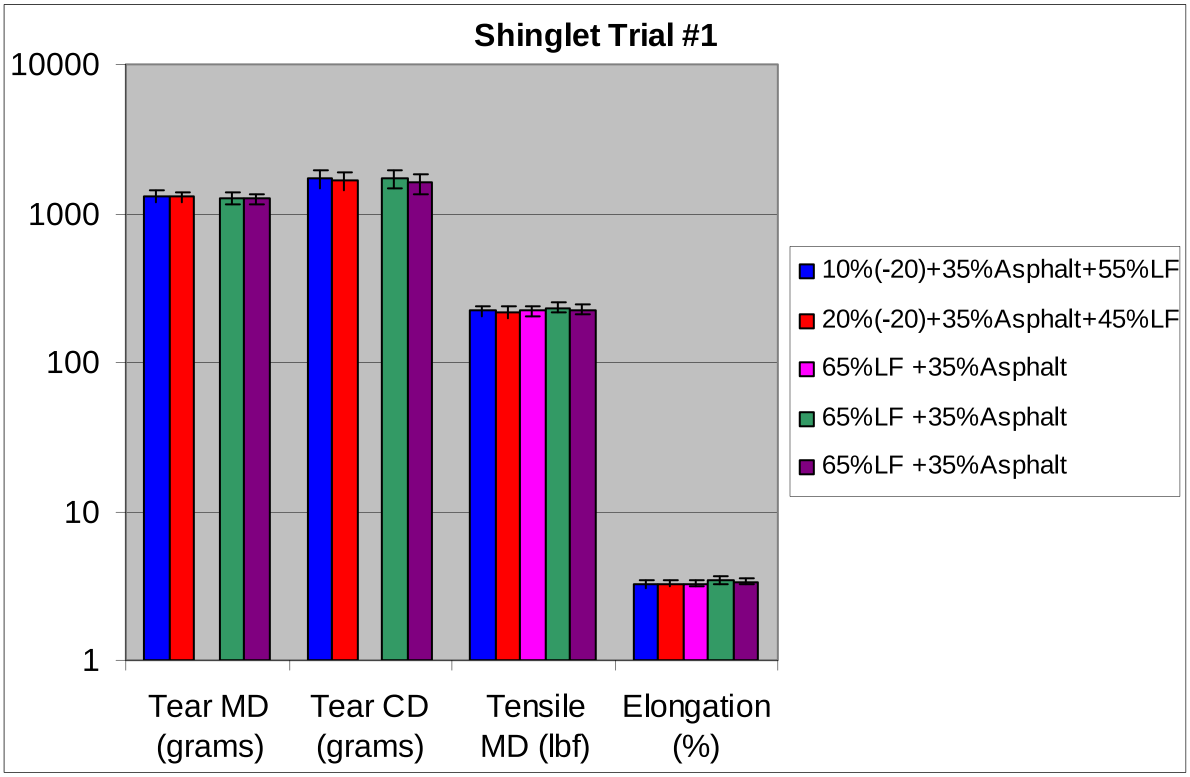


Fig. 2: Mechanical properties of shinglet samples using recycled shingles as a filler substitute. Error bars represent one standard deviation.

Filler and Asphalt Substitution: Shinglet Trial #2

A second shinglet trial was conducted investigating the potential of using the recycled shingle as an asphalt substitute in addition to a filler material substitute. The recycled shingle contains over 20% asphalt as seen in Table 2, which has the potential to replace some of the coating asphalt. This would likely lead to a tremendous cost savings with asphalt prices continuing to rise and the large price difference between fillers and asphalt. Like the initial trial, a control sample was made. The filled coating made with recycled shingle was composed of 33% asphalt, 57 % limestone filler, and 10% -20/+50 mesh recycled shingle.

The mechanical property testing of the shinglet samples are shown in Fig. 3. The results do not show a significant change in the mechanical properties when 2% less of the coating asphalt is used.

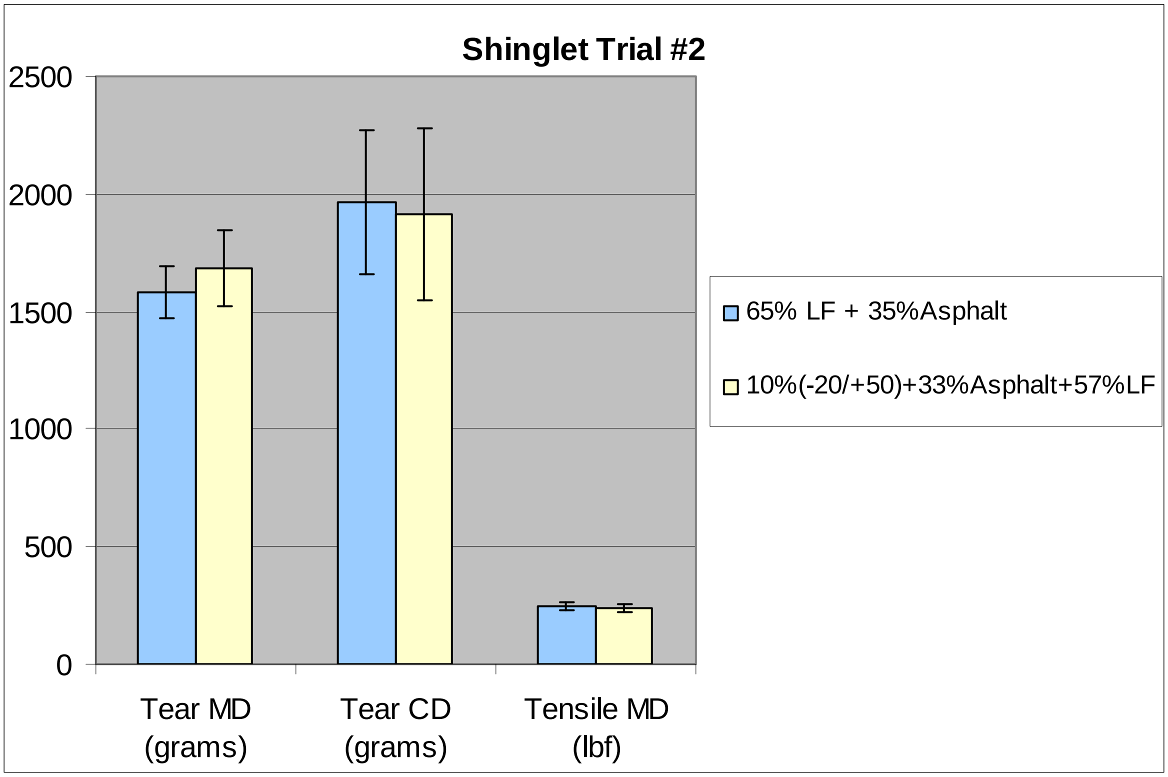


Fig. 3: Mechanical properties of shinglet samples using recycled shingle as a filler and asphalt substitute. Error bars represent one standard deviation.

The encouraging results of the shinglet trial were complemented by viscosity measurements performed by Summit that demonstrated only a slight increase in filled coating viscosity (see Table 3). The increase in viscosity is likely attributed to the glass fibers contributed by the recycled shingle and is likely to continue to increase with higher levels of recycled shingle.

The results of the shinglet trials demonstrate that both the -20 and -20/+50 mesh fractions showed no significant differences in mechanical properties (Fig. 3). Thus it was expected that the -50 mesh fractions would not show any deterioration of shinglet properties either. However, the results can only be related to shingle performance to the degree that the shinglet line represents the manufacturing of a shingle. A separate study showed one case of the shingle line accurately reproducing trial data trends, but caution must still be used, especially because the referenced case only changed the filler particle size and did not change filler or asphalt chemistry.

Table 3: Filled coating viscosity results using recycled shingle as a raw material substitute.

	35%Asphalt+65% LF	10%(-20/+50)+33%Asphalt+57%LF	100%Asphalt
	Control	Filler and Asphalt Substitution	
Log ID	2032238	2032237	2032239
Minutes	Viscosity (centipoise)		
5	5237.5	5337.5	500.6
6	4987.5	5175	
7	4825	5087.5	
8	4762.5	5025	

Further Development

While the initial investigation into the use of ground up recycled shingle as a material substitute for limestone filler and asphalt is promising, there are still many issues that need to be addressed. A trial at a roofing plant needs to be completed to verify the findings from the shinglet line that the recycled shingle does not deteriorate the shingle performance. The plant trial will also help clarify any processing, material handling, and transport issues. Further studies are also needed on the weathering and durability of the shingle, especially if the recycled shingle is going to be used as an asphalt substitute.

Additionally, there may also be issues with asphalt compatibility due to the asphalt from the recycled shingle being oxidized and likely from a different crude source. Another concern lies in the consistency of the source of recycled shingle. The material will be limited to whatever roof tear-offs that are occurring in the area. This will result in shingles that are different in age and manufacturers, which will influence the composition of the resulting recycled shingle.

These above issues will need to be addressed from a technical standpoint, but additional concerns lie in the sourcing aspect of finding a supplier in close proximity to the roofing plant, the quantity of recycled shingle to be delivered, and the price at which it can be delivered.

Summary and Conclusions

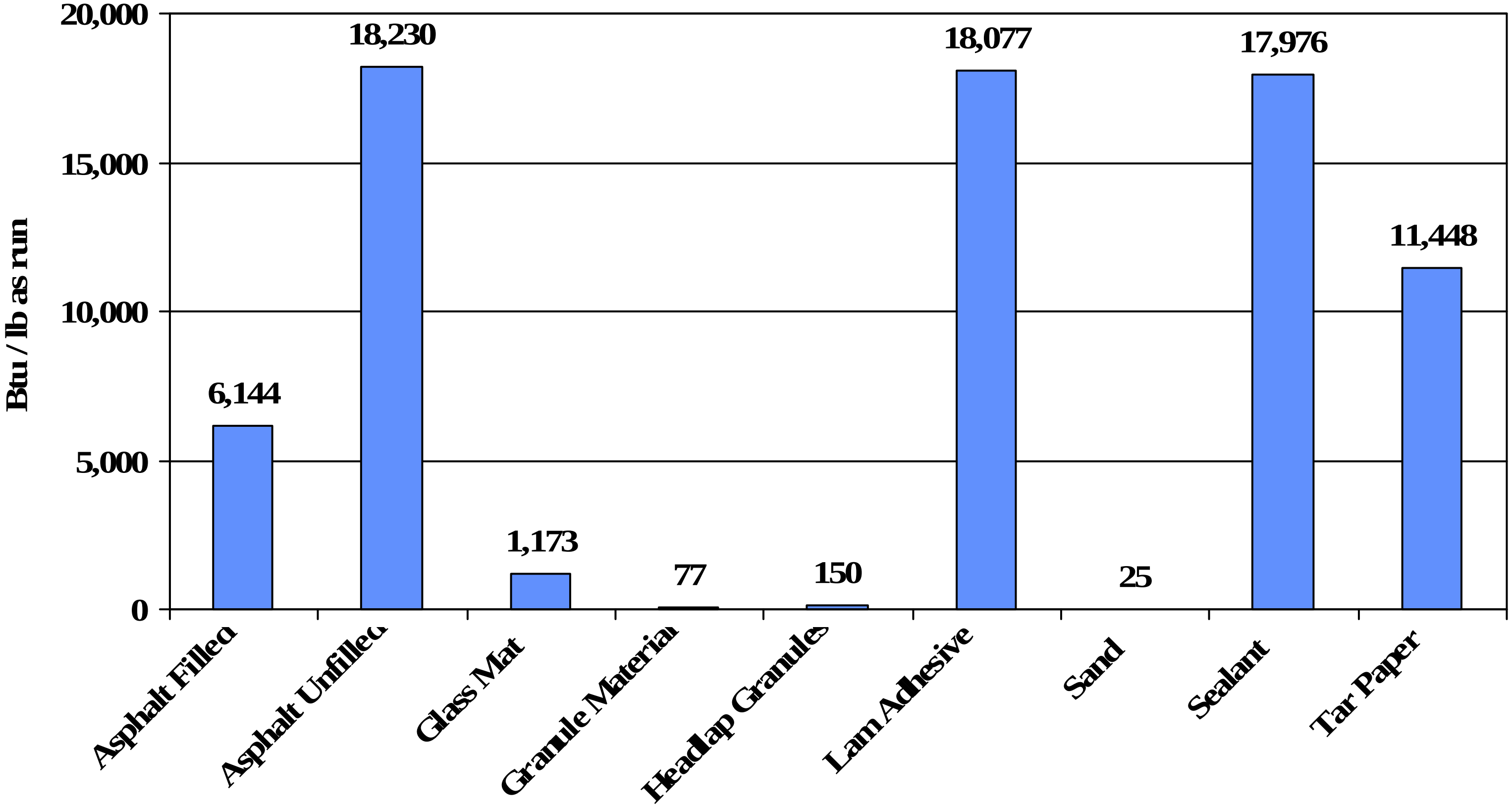
The preliminary studies reveal that there is an opportunity to use recycled shingle as a raw material substitute for limestone filler and asphalt. There is a great financial incentive to be able to use the asphalt content from the recycled shingle to displace the virgin asphalt compared to only using the recycled shingle as a filler substitute. While the material substitution shows financial promise, there are also many processing and sourcing hurdles to overcome to implement this at a roofing plant. First and foremost, further testing is essential, especially on a plant processing line, to solidify the results of the lab tests that have been completed.

APPENDIX G
Shingle Heat Content Study

Conducted by Owens Corning

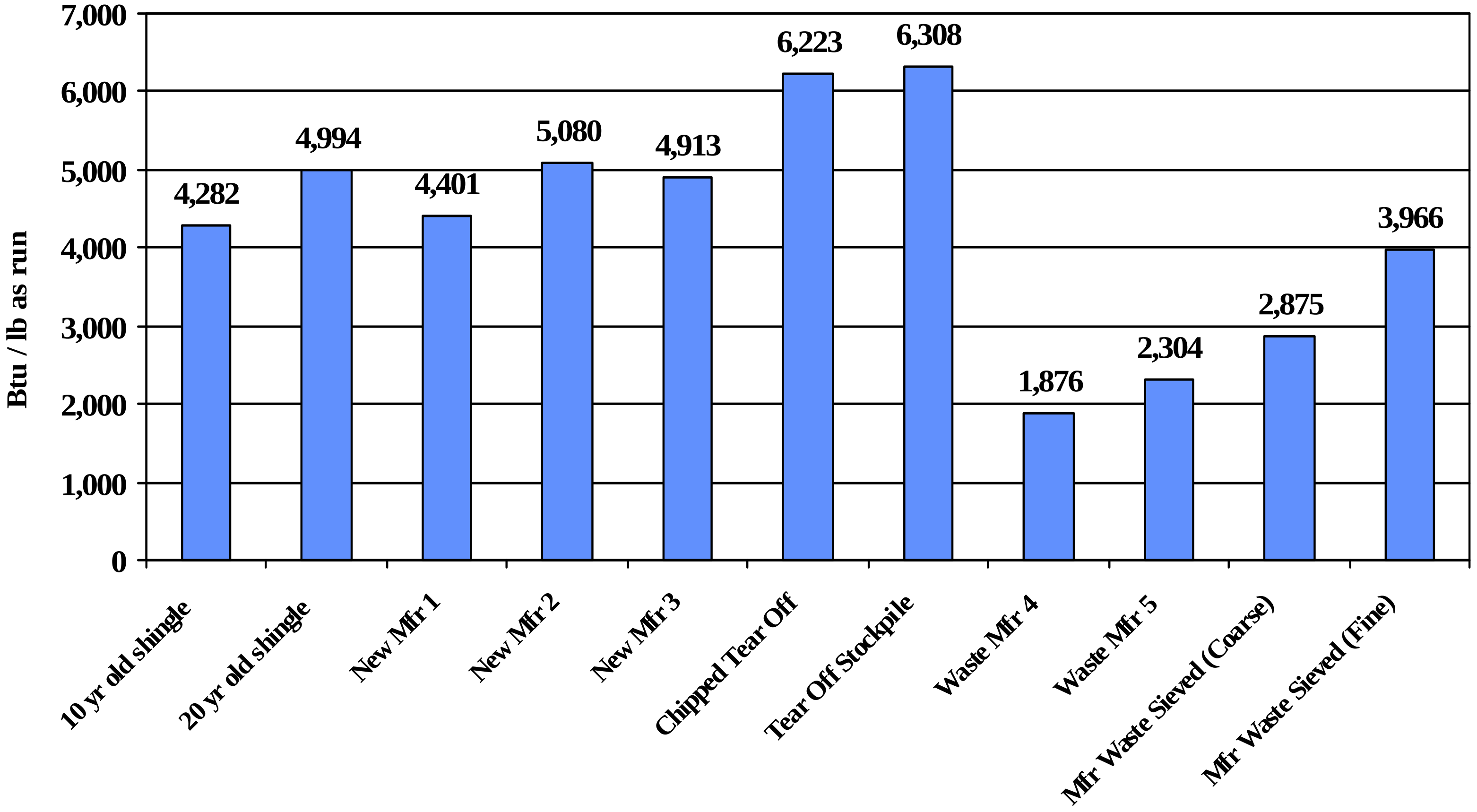
Science & Technology Center

Potential fuel value of shingle raw materials determined by well accepted industry standard testing procedure



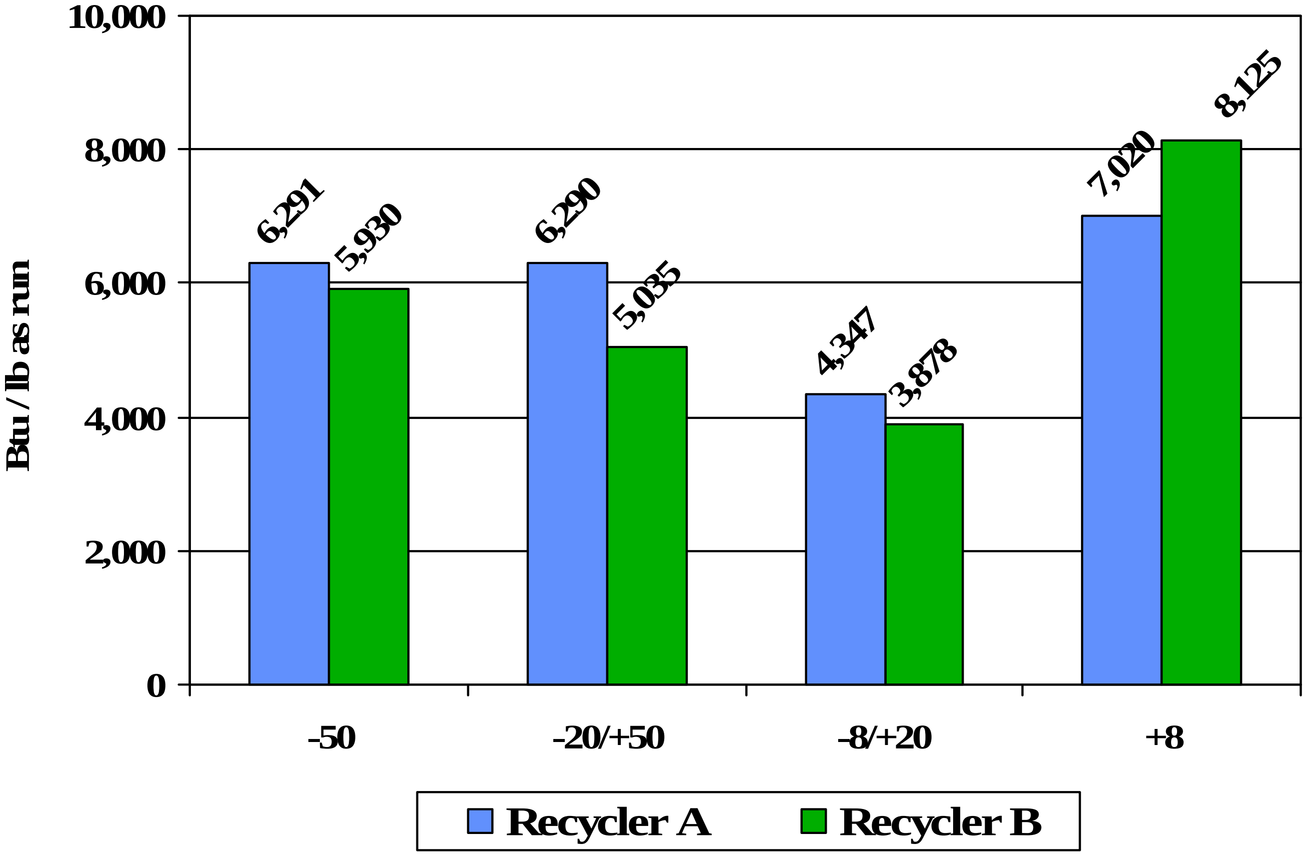
Average Bomb Calorimeter Results on Individual Raw Materials Typically Used in Shingle Manufacture (6/19/06)

Potential fuel value of shingle waste may vary depending on actual content (e.g. organics)



Bomb calorimeter results on manufactured waste & tear-off (6/19/06)

Fuel value can be optimized by varying sieve size



Bomb calorimeter Results on tear-off sieved into different sizes
Facilities A & B (7/26/06)

Appendix H

Other Useful Information :
Enhanced Recovery of Roofing Materials

AthenaInstitute

ENHANCED RECOVERY OF ROOFING MATERIALS

Prepared for:

CANADIAN CONSTRUCTION INNOVATION COUNCIL

By:

ATHENA SUSTAINABLE MATERIALS INSTITUTE

January, 2007

Executive Summary

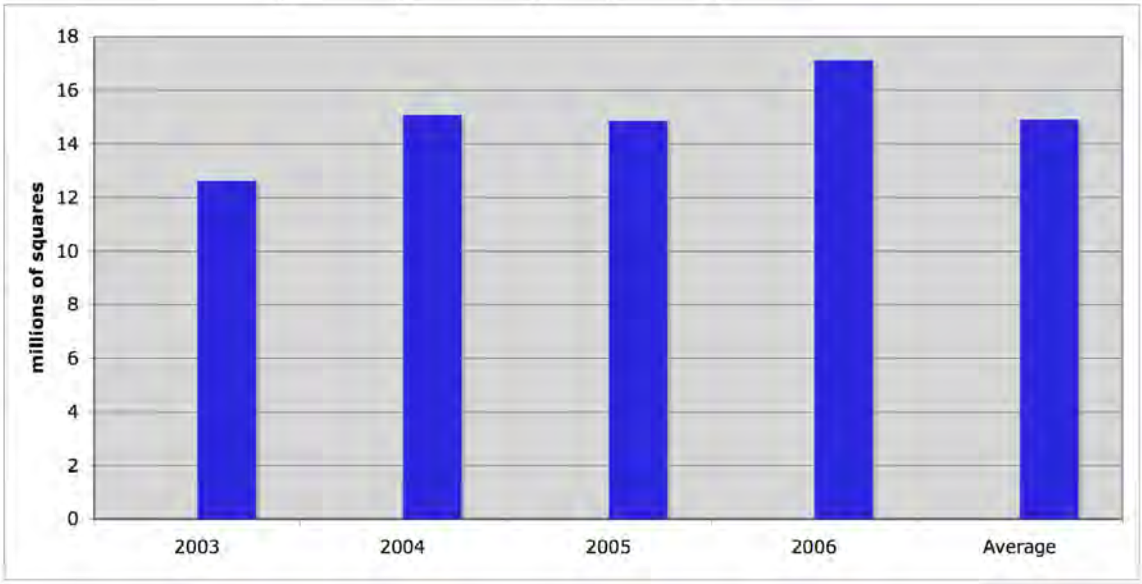
This briefing paper has been prepared to support the development of an implementation plan for increasing the recovery of end-of-life roofing materials. The paper is intended as an introductory status update on the quantity of roofing scrap available in Canada, potential end-uses for this scrap, and the various economic and environmental drivers that may influence future recycling and reuse. A workshop, to be held in Toronto in February, 2007, will focus on the various barriers to be overcome (e.g., regulation, legislation, technological, economic and environmental) to make roofing scrap recycling a market reality.

This paper concentrates on asphalt based roofing products, which make up 90% of the residential market and as much as 80% of the low slope (ICI) roofing market in Canada.

Canadian Residential Asphalt Roofing Market & Scrap Production

Between 2003 and 2006, Canadian asphalt shingle consumption increased steadily and mirrored the growth in new housing starts. On average, approximately 15 million squares[1] of asphalt shingle roofing are installed in Canada annually (see Chart ES1 below). Regionally, Central Canada (Ontario and Quebec), Alberta plus British Columbia, and the combined Prairie and Maritime provinces have accounted for 65%, 20% and 15% of asphalt shingle consumption over the last four years, respectively. IKO and BP-EMCO are the two Canadian manufacturers of asphalt shingles, but there is considerable Canadian and U.S. trade, with almost equal quantities of asphalt shingles flowing in both directions.

Chart ES1 Canadian Asphalt Shingle Consumption (2003-06)



Re-roofing accounts for the largest share of the annual asphalt shingle market in both Canada and the U.S., estimated at 80% by the Canadian Asphalt Shingles Manufacturers'

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[1] One square is equivalent to 100 square feet of roof area.

Association (CASMA) and at 80 to 85% in the U.S. by the Asphalt Roofing Manufacturers' Association (ARMA). Re-roofing generates a corresponding large volume of scrap material, estimated at 7 to 10 million tons (6 to 9 million metric tonnes) of shingle tear-off waste and installation scrap in the U.S.

Table ES1 below summarizes our estimate of annual Canadian residential asphalt shingle tear-off (re-roofing), new construction scrap, and related organic felt scrap quantities. The annual total comes to 1.25 million tonnes of scrap asphalt shingles and saturated felt.

Table ES1 – Annual Generation of Asphalt Shingle and Organic Felt Waste in Canada

	Units	Quantities	Notes
Total An. Roof Squares (mill. of squares)	MMsq	15	
new construction (@ 20% of market)	MMsq	3	
tear-offs (@ 80% of market	MMsq	12	
Mass of shingles per square	m t	0.102	(225 lbs installed)
Mass of felt per square	m t	0.0035	(15 lbs installed)
Total scrap - asphalt shingles			
from new construction	m t	4,590	est. @1% of mass
from tear-offs	m t	1,224,000	
Total scrap - organic felt			
from new construction	m t	7,350	est. @14% of mass
from tear-offs	m t	21,000	Est. based on 50% of roofs use felt
Grand Total asphalt shingle/felt scrap	m t	1,256,940	

Notes: MMsq- millions of squares, m t – metric tonnes
New construction asphalt shingle scrap estimated by the Athena Institute
New construction organic felt scrap estimated by the Athena Institute

Canadian Industrial, Commercial and Institutional (ICI) Asphalt Roofing Market & Scrap Production

The Canadian industrial, commercial and institutional (ICI) roofing market, typically categorized as a low-slope roofing market, uses a vast array of roofing products and systems. There are conventional roofs and protected membrane roofs, single and multiple ply roofs, and numerous types of membranes and built-up roof (BUR) systems. Roofing asphalt is prominent in three types of systems – traditional 4-ply built-up roofs, 2-ply modified bitumen roofs, and rubberized asphalt roof. Modified bitumen and asphalt built-up roofs combined account for as much as 80% of the annual Canadian ICI low-slope roofing market. The Canadian Roofing Contractors' Association (CRCA), the primary national industry association for the ICI sector, estimates that Canadian commercial roofing sector sales approach $1.6 billion on an annual basis. They also estimate that roof replacement accounts for approximately 60% of all activity in the sector, with new roof installations accounting for the remaining 40% of the market. A small portion of the roof replacement segment includes roof repairs.

Table ES2 below, which provides the Institute's estimate of annual asphalt roofing scrap for the ICI sector, shows that new asphalt roofing activity contributes a very small portion to the overall waste stream. Overall, we estimate that a total of 330,000 tonnes of asphalt related roofing scrap is produced by the sector annually, with re-roofing responsible for 99% of the total waste stream.

Table ES2 ICI Sector Calculated Annual Asphalt Roofing Related Wastes

	Units	**Quantities**	**Source**
Total ICI Sector Sales Value	$ millions	1600	P. Kalinger
new construction (@ 40% of market)	$ millions	320	P. Kalinger
replacement (@ 60% of market	$ millions	1280	P. Kalinger
Average cost of BUR/Mod.Bit. Roofs	$/ square	380	P. Kalinger
New construction no. of squares basis	squares	842,105	
Replacement no. of squares basis	squares	3,368,421	
Total Scrap in New Construction			Waste factor
unsaturated organic felt use	tonnes	1,117	at 14%
asphalt saturant use in felt	tonnes	1,391	at 14%
asphalt interply and flood coat use	tonnes	547	at 1%
asphaltic primer	tonnes	63	at 5%
aggregate ballast	tonnes	-	
Total	**tonnes**	**3,119**	
Total Scrap from Replacement			**%**
unsaturated organic felt	tonnes	28,724	9%
asphalt saturant in felt	tonnes	35,773	11%
asphalt interply and flood coat	tonnes	197,053	59%
asphaltic primer	tonnes	4,547	1%
aggregate ballast	tonnes	62,585	19%
Total	**tonnes**	**328,682**	99%
Total ICI Sector Asphalt Roofing Scrap	**tonnes**	**331,801**	

Notes: Average cost of BUR ($3.50/sq.ft.), Mod.Bit ($4.25/sq.ft.) at equal market share = $3.80/ sq.ft.x100=$380/roofing square, Used a replacement quantity of 90% to account for repair activity

Total Asphalt Roofing Scrap Production by Component

Table ES3, below, summarizes the total annual asphalt based roofing scrap available in Canada by primary component. Although the ICI sector's roofing scrap output is only about 25% of that estimated to be produced by the residential sector on a mass basis, the amount of asphalt in the ICI roofing scrap is almost 75% that of the residential market on a percentage of asphalt basis, making it a significant consideration for recycling. Overall, an estimated 1.5 million tonnes of asphalt related roofing waste is generated in Canada, with aggregate, asphalt and organic felts representing 57%, 35% and 9% by mass, respectively.

Table ES3 Annual Residential & ICI Asphalt Based Roofing Scrap by Component

Component	**Residential**		**ICI**		**Total**	
	m tonnes		m tonnes		m tonnes	
Unsaturated org. felt	109,627	9%	29,841	9%	139,468	9%
Asphalt	311,872	25%	239,384	72%	551,256	35%
Aggregate/Granules	835,441	66%	62,585	19%	898,026	57%
Total	1,256,940	100%	331,810	100%	1,588,750	100%

End-uses for Asphalt Roofing Scrap

Eight potential end-use markets were identified for Residential and ICI asphalt roofing scrap: hot-mix asphalt (HMA); cold patch; dust control on rural roads; temporary roads; driveways and parking lots; aggregate base; fuel; and new roofing shingles. The benefits of recycling asphalt based roofing products include conservation of landfill space and resources, reduced costs of disposal, and lower costs of production as compared to new roofing products made from virgin materials. Some of the obvious risks associated with establishing an asphalt recycling facility are uncertain capital costs, permitting problems or delays, highly variable material supply and sources, and undeveloped and/or under-developed markets.

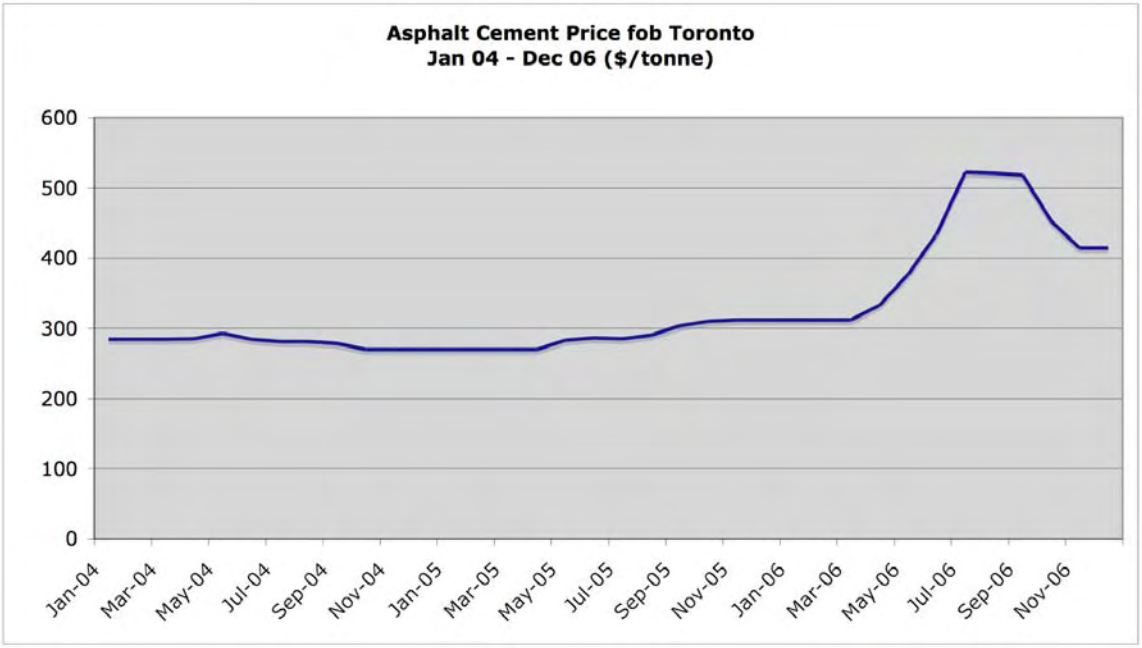
In Canada, asphalt based roofing scrap has been incorporated in HMA, trail construction and as a fuel in cement kilns. By far the largest end-use market for scrap asphalt roofing products in North America is the hot-mix asphalt industry and road construction. Numerous states and some provinces (Ontario and Nova Scotia) have provisions for using recycled asphalt shingles in HMA. Although HMA specifications have typically allowed for the use of only uncontaminated manufacturers' scrap shingles (cut outs and off spec shingles) at up to 5% of the HMA mix, more state and provincial transportation authorities are accepting tear-off scrap in their HMA specifications. It is estimated that there are over 500 hot-mix asphalt plants across Canada producing in the order of 30 to 31 million tonnes annually. Substitution of 5% of the virgin material in hot-mix asphalt could consume in the order of 1.5 million tonnes of asphalt roofing scrap; in other words, the total asphalt roofing scrap generated in Canada annually. Further, it is estimated that substituting 5% roofing scrap for virgin asphalt concrete would eliminate 90,000 tonnes of greenhouse gases produced by the HMA industry. Obviously, the HMA sector is a potentially large, and therefore a key market to focus on when assessing asphalt based roofing scrap recycling.

Economic and Environmental Drivers

The HMA industry has experienced a considerable increase in asphalt cement prices in recent months (see Chart ES2). Perhaps the most significant reason for this increase is the relatively large increase in gasoline, diesel fuel (see Chart ES3) and home heating oil prices, which makes it economical for refiners to invest in facilities to further refine the heavy end of the crude oil barrel from which asphalt cement is derived. U.S. and Canadian refineries have invested hundreds of millions of dollars in the last few years in cokers for this type of conversion. As a result, long-term supply of asphalt cement may become an issue, driving up those prices and creating more incentive for recycling.

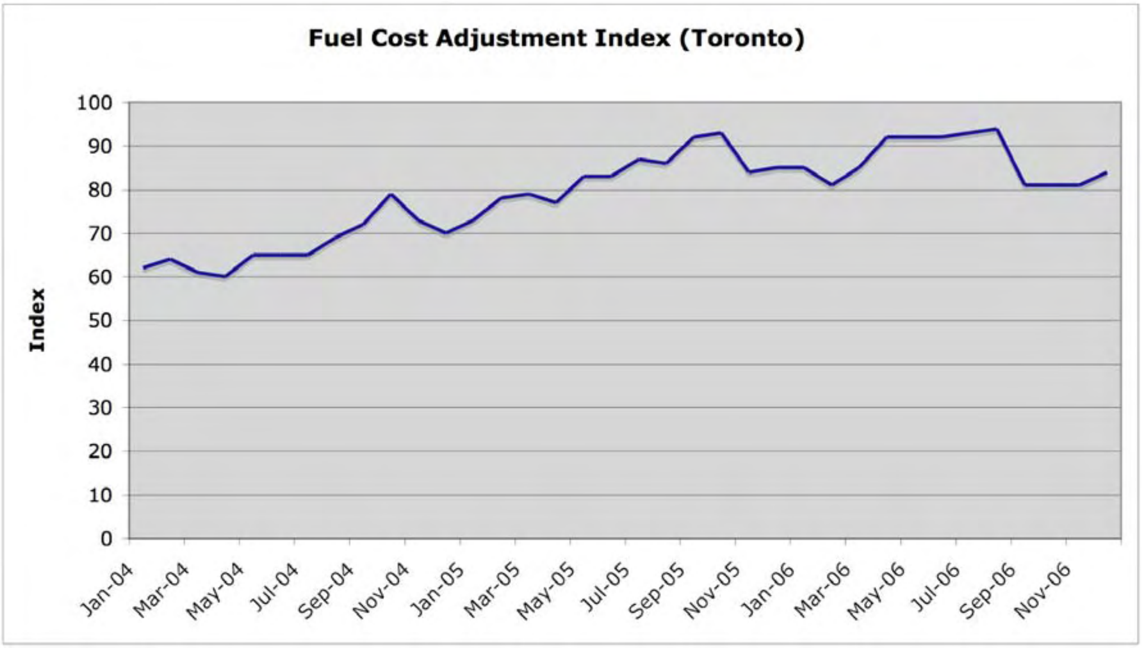
Other significant drivers toward more recycling of roofing materials include diminishing landfill capacity and increasing tipping fees for construction and demolition waste. On the negative side, there is the difficulty obtaining operating permits for recycling facilities and a lack of diversion incentives.

Chart ES2 Recent Asphalt Cement Prices, FOB Toronto



Source: Ministry of Transportation Ontario (PG Grade 58-28 or equivalent)

Chart ES3 – MTO Diesel Fuel Cost Adjustment Index[2] for Toronto



Source: Ministry of Transportation Ontario

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[2] The Fuel Cost Adjustment Index is based on the price, including taxes, FOB Toronto area terminals for low sulphur diesel – MTO.

GLOSSARY OF ACROYNMS AND TERMS

AASHTO - The American Association of State Highway and Transportation Officials
An organization of highway engineers from 50 U.S. states that develops guides and standards, including specifications for utilizing manufacturer and tear-off asphalt shingle scrap in HMA

Aggregate
Hard, inert mineral material, such as gravel, crushed rock, sand, or crushed stone, used in pavement applications either by itself or for mixing with asphalt

Aggregate Base
Well-graded aggregate suitable for compacting to such a degree that it provides a firm, stable base

APP – atactic polypropylene
Modifier used in modified bitumen roofing membranes

ARMA - Asphalt Roofing Manufacturers' Association

ASRAP - Asphalt Shingles Research Assessment Project

Bitumen
A class of black or dark-coloured (solid, semisolid, or viscous) cementitious substances, natural or manufactured, typically composed of asphalts, tars, pitches, and asphaltites

BTU - British Thermal Unit
A unit of energy

BUR - Built-Up Roofing Membrane
Four layers of either fibreglass mat or organic felt, with asphalt applied between plies and a flood coat over top

CASMA - Canadian Asphalt Shingles Manufacturers' Association

CCME - Canadian Council of Ministers of the Environment

CMRA - Construction Materials Recycling Association

Cold Patch
Aggregates and liquid bitumen vulcanized at room temperature, activated by chemical agents without the application of heat from an outside source and stockpiled for patching or maintenance

Conventional Roofing System
A roofing system on which the membrane is located above the insulation

CRCA - Canadian Roofing Contractors' Association

DOT - Department of Transportation

Elastomer
A material that, after being stretched, will return to its original shape

EPDM – ethylene propylene diene monomer
A family of resins based upon olefinic monomers. Used in single ply roofing membranes

EPR - Extended Producer Responsibility

Fibreglass Mat
Fibres condensed into strong, resilient mats for use in roofing materials

Fibreglass Shingle
A shingle with a woven fibreglass mat as the base material. The fibreglass mat is coated with asphalt on both sides then covered with ceramic granules

Hammermill
A high-speed size reduction mill for pulverizing an array of raw and waste materials for process or recovery. Utilizes a series of swinging hammers for cutting material

HMA – Hot-Mix Asphalt
A high-quality, thoroughly controlled, engineered mixture made by heating asphalt cement and mixing it with aggregates and mineral fillers. Hot-mix pavement design formulas usually contain between 5 and 7% bitumen

Hot Applied Rubberized Asphalt Membranes
A flexible, site applied membrane for use in waterproofing and roofing applications. It consists of proprietary blends of asphalt, mineral fillers, elastomers (natural, synthetic, or a blend of both), virgin or reclaimed oil, and a thermoplastic resin.

ICI - Industrial, Commercial and Institutional

Manufacturers' Scrap Shingle
Trimmings, overruns generated from manufacturing processes

Modified Bitumen
Rolled roofing membrane with polymer modified asphalt and either polyester or fibreglass reinforcement

NAPA - National Asphalt Pavement Association

NRCA - National Roofing Contractors' Association

Organic Shingle
A shingle that uses paper as the base material. The paper is saturated in asphalt and coated with ceramic granules on the top surface. The asphalt waterproofs the shingles

PMRA - Protected Membrane Roofing System
A protected membrane roof assembly, or inverted roofing system, is defined as a roof on which the membrane is located below the insulation

RAP - Reclaimed Asphalt Pavement
Pulverized excavated asphalt that is used as an aggregate in the recycling of asphalt pavements. Factory-rejected roofing shingles can be added to RAP

RAS - Recycled Asphalt Shingle
Shingle from post-consumer tear-offs; see TOSS

SBS Membranes
Modified bitumen membranes using styrene butadiene as modifier. Can be applied by torch or asphalt

Tipping Fee
A per-ton fee charged to haulers and citizens for waste delivered to a waste management facility such as a landfill or recycling depot

TOSS - Tear Off Shingle Scrap
Also known as post-consumer scrap shingle or RAS; shingle generated during the demolition or replacement of existing roofs; scraps of trimmed shingles

TPO
A chemical industry accepted designation for a family of thermoplastic resins created from basic olefinic monomers. Used in single ply TPO roofing membranes

Underlayment
Asphalt based rolled material designed to be installed under main roofing material, to serve as added protection

Acknowledgements

This report was made possible through the support of Natural Resources Canada and the Canadian Council of Ministers of the Environment. The Institute would like to thank Peter Kalinger of the Canadian Roofing Contractors' Association and Mr. Mike Vandenbusshe of the Canadian Asphalt Shingle Manufacturers' Association for their timely assistance with this report. We also would like to acknowledge the fine work done by the U.S. Construction Materials Research Association and their invaluable web resource <www.ShingleRecycling.org> without which we would not have been able to complete this project in the short time allotted.

Disclaimer

Although the Athena Sustainable Materials Institute has done its best to ensure accurate and reliable information in this report, the Institute does not warrant the accuracy thereof. If notified of any errors or omissions, the Institute will take reasonable steps to correct such errors or omissions. This report, while characterizing roofing industry scrap generation, its composition and avenues for roofing scrap recycling, does not claim to have investigated the environmental hazards associated with any described activities.

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APPENDIX A: ANNOTATED U.S. ASPHALT SHINGLE RECYCLING - PROJECT SUMMARY

1 Introduction

This briefing paper has been prepared to support the development of an implementation plan for increasing the recovery of end-of-life roofing materials. This briefing paper will serve as an introductory status update for a workshop to be held in Toronto in February 2007. Due to the prevalence of asphalt based roofing materials in both residential and industrial, commercial and institutional markets, the primary focus of this report is asphalt based roofing materials.

1.1 Objectives

The Canadian Construction Innovation Council engaged the Athena Institute to prepare this briefing paper with the intent of finding answers to the following questions:

- What potential quantities of asphalt based roofing materials can be deemed recoverable in Canada?
- Who in North America is recovering roofing materials and to what end-uses are these recovered materials put?
- What collection and sorting systems are typically used to divert roofing materials from landfills?
- To what extent are these collection and sorting systems specific to the eventual material end-use?
- What municipal ordinances are in place governing roofing material recovery?
- What, if any, are the environmental (e.g., regulations) or economic (e.g., landfill tipping fees, energy costs) determinants driving the recovery of roofing materials?

1.2 Literature Review and Gap Analysis

Over a two-week period in January 2007, the Institute conducted a web search for literature related to the recycling of asphalt based roofing products in North America. We also contacted relevant associations (Canadian Asphalt Shingles Manufacturers' Association and Canadian Roofing Contractors' Association), as well as others with involvement in the recycling of roofing materials (e.g., Canadian municipalities regarding ordinances concerning asphalt roofing product recycling). In some instances we found considerable information (e.g., recycling of asphalt shingles in hot-mix asphalt), while in other instances there was a dearth of information. At various points in the report, gaps in the data or information concerning asphalt roofing product quantities or recycling end-uses are acknowledged as a way to identify future research efforts in this field.

1.3 Report Structure

The remainder of this report is structured as follows.

Sections 2 and 3, respectively, describe the residential and ICI asphalt roofing sectors in Canada, including applicable sector asphalt products and estimates of the roofing scrap from these sectors.

Section 4 describes various end-uses for asphalt roofing scrap.

Section 5 describes some of the major economic and environmental drivers affecting asphalt roofing scrap recycling.

2 The Residential Asphalt Roofing Industry

2.1 Residential Roofing Products

2.1.1 Asphalt Shingles

The residential asphalt roofing industry started in the 1890s with bitumen and coal tar pitch impregnated roofing felts[1]. Two weights of roofing felts, #15 and #30, are still used today in residential and industrial, commercial and institutional (ICI) applications. The popular 3-tab asphalt shingle had been invented by 1915. From these modest beginnings, asphalt roofing became the most readily used and accepted roof covering material in North America. According to the Asphalt Roofing Manufacturers' Association (ARMA), more than 80% of all residential roofs in the United States are covered with asphalt roofing industry products. In Canada, this number is even higher – estimated at 90% of all residential roofing applications.

In the early 1950s, there were 11 manufacturers of asphalt roofing products in Canada. Over the years, the industry underwent considerable consolidation, and by the early 1980s there were four producers left. Today only two remain: Building Products, a division of EMCO Limited; and IKO Industries Ltd.

Building Products (BP) operates two plants – one in LaSalle, QC, the other in Edmonton, AB. Since the late 1980s, BP has been a part of EMCO Limited, Canada's largest plumbing and HVAC wholesaler. BP also operates a paper felt mill in Pont Rouge, QC. IKO Industries, a family-owned manufacturer of residential and commercial roofing products, has grown from modest beginnings in the early 1950s to become the largest roofing manufacturer in Canada. It supplies the market from its plants in Calgary, AB, Brampton, ON and Hawkesbury, ON. Its newest roofing plant in Sumac, WA, is just south of the Canadian border, supplying not only the US Pacific Northwest, but also the British Columbia market. In 1993, IKO also purchased former CGC roofing plants in Toronto, ON and Winnipeg, MB. IKO is a vertically integrated company, producing its own felts in Brampton, ON, Calgary, AB, and Monroe, MI, its roofing granules in Madoc, ON and controlling its source of asphalt. IKO also operates a number of roofing plants in the U.S. (recently forming a joint venture with Owens Corning) and Europe.

In British Columbia, there is also a felt producer, HAL Industries Inc., with factories in Surrey and Burnaby (HAL does not manufacture asphalt shingles or mineral roll roofing). The company produces saturated felts for built-up roofing (BUR) applications, SBS (styrene butadiene) modified torch-on roofing and waterproofing sheets; in addition, some of the #15 felt HAL Industries produces is undoubtedly used as asphalt shingle underlayment.

Canadian roofing manufacturers are members of CASMA, the Canadian Asphalt Shingles Manufacturers' Association, and associate members of CRCA, Canadian Roofing

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[1] Much of this section comes from the Athena Institute's report entitled, "Life Cycle Analysis of Residential Roofing Products," prepared by Venta, Glazer Associates in 2000.

Contractors' Association. Due to their manufacturing and export interest in the U.S., they also participate in equivalent organizations there: ARMA (Asphalt Roofing Manufacturers' Association) and NRCA (National Roofing Contractors' Association).

2.1.2 Types of Asphalt Shingles

Asphalt roofing shingles come in many different types, weights and shapes. The weight of asphalt shingles can vary between 125 lbs. (57 kg) and 380 lbs. (173 kg) per square of roof covered [2]. The principal reason for the difference is the number of plies of roofing felt with asphalt saturant, coating and granules in the completed roof.

The most common form of asphalt shingles is strip or 3-tab shingles. They are rectangular in shape, the most prevalent sizes being 1000mm by 336mm (39 3/8" by 13 1/4") metric shingles and 12" by 36" shingles. They generally have three tabs that are exposed along the length of the shingle for visual effect. Shingles may also be embossed to give a more upscale, heavier appearance (referred to as architectural shingles). Shingles may be produced in single thickness or with more than one thickness; these are generally known as laminated shingles. Such shingles provide a more three-dimensional appearance. The term self-sealing refers to the addition of a strip of factory applied adhesive on the back of the shingle; the adhesive is activated by the sun's heat after installation and "seals" each shingle to the one below it. This provides the roofing system with greater wind resistance. Another way to achieve wind resistance is through the use of interlocking shingles, which rely on the locking mechanism of the tabs instead of a sealant for their wind resistance.

Back in 2000, at least 65% of the shingles produced in Canada were of the basic 3-tab self sealing variety, with about 15% each of the laminated and architectural shingles being produced, and 5% of the specialty interlocking shingles. Many in the industry believe that laminated and architectural shingles have increased their share of total shingle production, but production by shingle type is not reported by either IKO or BP. This is significant as the range of weights vary by type, with the laminated and architectural shingles being of the heavier variety. CASMA estimates that the average asphalt shingle bundle weighs 75 lbs. (34 kg), but the range can be from 60 lbs. (27 kg) to 85 lbs. (39 kg) per bundle[3]. Using CASMA's average weight per bundle and assuming three bundles per square of roofing (100 sq. ft.), a typical square of installed asphalt shingle roof will weigh 225 lbs. (102kg). BP produces eight asphalt shingle types (with varying warranties) ranging between 215 lbs. (98 kg) and 310 lbs. (141 kg) per square of roof; IKO produces over 16 different types, ranging between 213 lbs. (97 kg) and 300 lbs. (136 kg) per square of roof. As a result, the type of shingle used will have a significant bearing on the installed weight of the roof and the amount of asphalt shingle waste calculated when it is eventually removed and replaced. CASMA's average weight per square of roof would indicate the use of a shingle with a 20 to 25-year warranty.

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[2] One roofing square is equal to 100 square feet.

[3] Personal correspondence, Mike Vandenbusshe, CASMA.

Lastly, asphalt shingles may be produced using either organic felts or glass mats. Traditionally, asphalt shingles incorporating organic felts have dominated the Canadian residential roofing market due to their greater flexibility in cold weather (90% of the Canadian market). However, glass mat based asphalt shingles are the product of choice in the U.S. and are making inroads into the Canadian market. In the foreseeable future, however, the majority of roof tear-off waste shingles will primarily be organic based shingles.

2.1.3 Other Residential Asphalt Roofing

Saturated organic felt

An asphalt saturated felt is used as underlayment for asphalt shingle roofs as well as other roof types (e.g., metal roofing). Rolls have markings to guide overlapping. The most common grades are #15 and #30 asphalt felts. The grade numbers indicate the weight of saturated felt per square of roof covered (e.g., #15 felt when applied to one square of roof would weigh 15lbs. (6.8 kg) per square of roof.

Roll roofing

Mineral surfaced roofing roll is comprised of a heavy duty felt base with asphalt, covered with mineral granules. It can be used as a roof covering membrane, for valley flashing or as a starter strip at the eaves of asphalt shingle roofs.

2.1.4 Residential Asphalt Roofing Product Components

All asphalt roofing incorporates at least two of the following three primary materials.

1. **Carrier sheet**, which can be either organic paper felt or fibreglass mat, provides a base and reinforcement for the bituminous weatherproofing, and gives the finished product appropriate strength and handling and application properties (rigidity and flexibility). Organic paper felt consists of both virgin and recycled cellulosic (wood, cardboard, paper) fibres. Asbestos based roofing felts were once used by the roofing industry, but were completely eliminated from the industry once the health problems related to asbestos fibres became known. Glass mats were introduced over the last couple of decades. The bonding of glass fibre filaments with phenol formaldehyde or urea formaldehyde resin produces the glass mat used in the roofing industry. All three asphalt based residential roofing products incorporate felts or mats.

2. **Bituminous materials**, primarily petroleum asphalts, are used for weatherproofing the felts because of the outstanding combination of waterproofing, preservative and cementing qualities. Asphalt is a co-product of petroleum refining, which produces a large number of chemicals through a complex set of physical and chemical processes. In North America, the dominant products of refineries are fuels. In recent years, the category of “asphalt and roofing oils” has accounted for less than 3% annually of the output of the U.S. petroleum refineries (due to data confidentiality, no comparable data is available on Canadian refinery operations). Asphalt is the bottom fraction remaining after all lighter fractions of fuels and oils have been distilled off. This heavier fraction

of the crude petroleum is further processed into a number of products, including asphalt, via a combination of distillation, solvent extraction and solvent de-asphalting. Practically, refineries will produce a number of asphalt grades. To attain the saturant and coating grades of proper softening point consistencies, air is blown at elevated temperatures through the asphalt, usually by the roofing operations themselves.

Asphalt impregnates and coats the carrying sheet of felt, providing the long term weatherproofing and performance desired in roofing products. Organic felts are first saturated using asphalt that fully impregnates the cellulosic fibres and the spaces between them, then coated with harder, more viscous coating asphalt. Glass mats are rather thin and non-absorbent, requiring no saturant. The mat sheet is usually perforated, allowing the complete encapsulation by the coating asphalt only. Coating asphalt, in addition to providing the weathering medium, may also provide the embedment layer for mineral granule surfacing.

3. **Mineral surfacing materials** include roofing granules, fine stone chips, or natural and baked on ceramic coatings on the exposed side of the asphalt product. Surfacing has a number of different functions: it protects the asphalt coating against the effects of solar radiation, extending the lifespan of the roof; it increases the fire resistance of the shingles; and lastly, it provides visually attractive surfaces through the selection and combination of various granule types and colours. Talc or mica is applied to the back side of asphalt shingles and mineral roll roofing to prevent sticking in the bundle or roll during storage and transport prior to application – after which, the self adhesive mastic cements the shingles together.

   There are other raw materials used in the production of residential asphalt roofing products. Mineral stabilizers and fillers, usually finely ground limestone or mineral dust from the production of roofing granules, are used in the coating asphalt.

2.1.5 Residential Asphalt Roofing Product Material Composition

The following Table sets out the raw material composition for three typical residential roofing products. It should be noted that the organic asphalt roofing shingle formulation was adjusted to agree with CASMA's average product usage per roofing square (100 sq. ft.).

Table 1 Residential Asphalt Roofing Product Formulations

lbs or kg/square	Organic Asphalt Shingles			#15 Organic Felt			Mineral Surface Roll		
	lbs/sq	kg/sq	%	lbs/sq	kg/sq	%	lbs/sq	kg/sq	%
Organic felt	17	8	8	6	3	40	9	4	8
Asphalt	54	24	24	9	4	60	26	12	23
Granules/filler	154	70	68	0	0	0	76	34	68
Total	225	102	100	15	7	100	111	50	100

Note: sq= one roofing square (100 sq. ft.)

2.2 Canadian Residential Roofing Market

This section describes the salient aspects of the Canadian residential roofing market. Overall, organic felt based asphalt shingles dominate the market. It is estimated that asphalt shingles represent close to 90% of the market, with wood shakes, metal roofing and a minor amount of asphalt roll roofing comprising the remaining 10% of the market. Statistics Canada tracks Canadian production, shipments and exports for the asphalt roofing sector (cat. No. 45-001-XIB). Statistics Canada and the CASMA are the primary sources used in this section of the report.

Table 2 below summarizes the production, shipments and exports of asphalt roofing products in Canada as reported by Statistics Canada for the four years 2003 through 2006.

Table 2 Canadian Asphalt Roofing Industry Production, Shipments and Exports

Production	**2003**	**2004**	**2005**	**2006**
Asphalt shingles	41,579,089	43,638,986	40,284,660	48,917,868
Smooth surfaced organic felt roll roofings	66,468	73,815	56,297	26,390
Mineral surfaced organic roll roofings	157,975	280,644	605,308	239,129
Asphalt saturated organic felts	96,401	98,480	88,106	84,809
Total shipments				
Asphalt shingles	42,096,229	47,693,282	44,299,711	51,350,951
Smooth surfaced organic felt roll roofings	76,357	67,512	62,009	54,571
Mineral surfaced organic roll roofings	338,518	402,842	377,720	385,367
Asphalt saturated organic felts	109,463	119,359	114,999	122,019
Exports				
Asphalt shingles	8,877,320	9,090,399	8,552,113	9,273,820
Smooth surfaced organic felt roll roofings	14,127	13,468	10,872	8,277
Mineral surfaced organic roll roofings	134,410	206,073	208,391	211,389
Asphalt saturated organic felts	55,353	58,513	60,182	62,188
Apparent Domestic Consumption				
Asphalt shingles	33,218,909	38,602,883	35,747,598	42,077,131
Smooth surfaced organic felt roll roofings	62,230	54,044	51,137	46,294
Mineral surfaced organic roll roofings	204,108	196,769	169,329	173,979
Asphalt saturated organic felts	54,110	60,846	54,817	59,831

Notes: Asphalt shingle reported on metric bundle basis (one metric bundle =3m^2 of roof coverage
Roll products reported on a metric roll basis (one metric roll = 10m^2 of roof coverage
Apparent consumption = Total Shipments – Exports (Dec 06 values estimated by CASMA)

Not all of the products in Statistics Canada's table above are used by the residential roofing sector. Smooth surfaced organic felt roll roofing can describe a number of products, including modified bitumen cap sheets and base sheets, which are used almost exclusively in the ICI roofing sector. Mineral surfaced roll roofing, while often used in the residential sector, may also be used in built-up roofing applications as a cap sheet. Saturated felts are used in both residential and ICI roofing applications. Table 3 presents the four-year average apparent Canadian consumption for these various products and converts them to a roof square (100 sq. ft.) basis. The table clearly shows that asphalt shingles comprise an overwhelming majority of the products used by the asphalt roofing industry. It should be noted that roofing asphalt as used in the ICI sector as a component in asphalt built-up roofs, in rubberized asphalt roofs, and as an adhesive in modified bitumen roofing is not reported by Statistics Canada for confidentiality reasons (see Section 3 for further information concerning the ICI market). In addition, these tables do not include imports of roofing materials, and it is known that a considerable amount of modified bitumen roofing and felts (organic and glass mat) as well as asphalt shingles are imported from the U.S. These data, as developed up to this point, should therefore be viewed as conservative.

Table 3 Average Apparent Consumption on a Roof Square Basis

Apparent Domestic Consumption	**4-yr Average**	**Roof Square Basis**	**% Contribution**
Asphalt shingles	37,411,630	12,068,268	97.42%
Smooth surfaced organic felt roll roofings	53,426	57,509	0.46%
Mineral surfaced organic roll roofings	186,046	200,265	1.62%
Asphalt saturated organic felts	57,401	61,788	0.50%
Total		12,387,830	100%

2.2.1 Asphalt Shingle Roofing Market

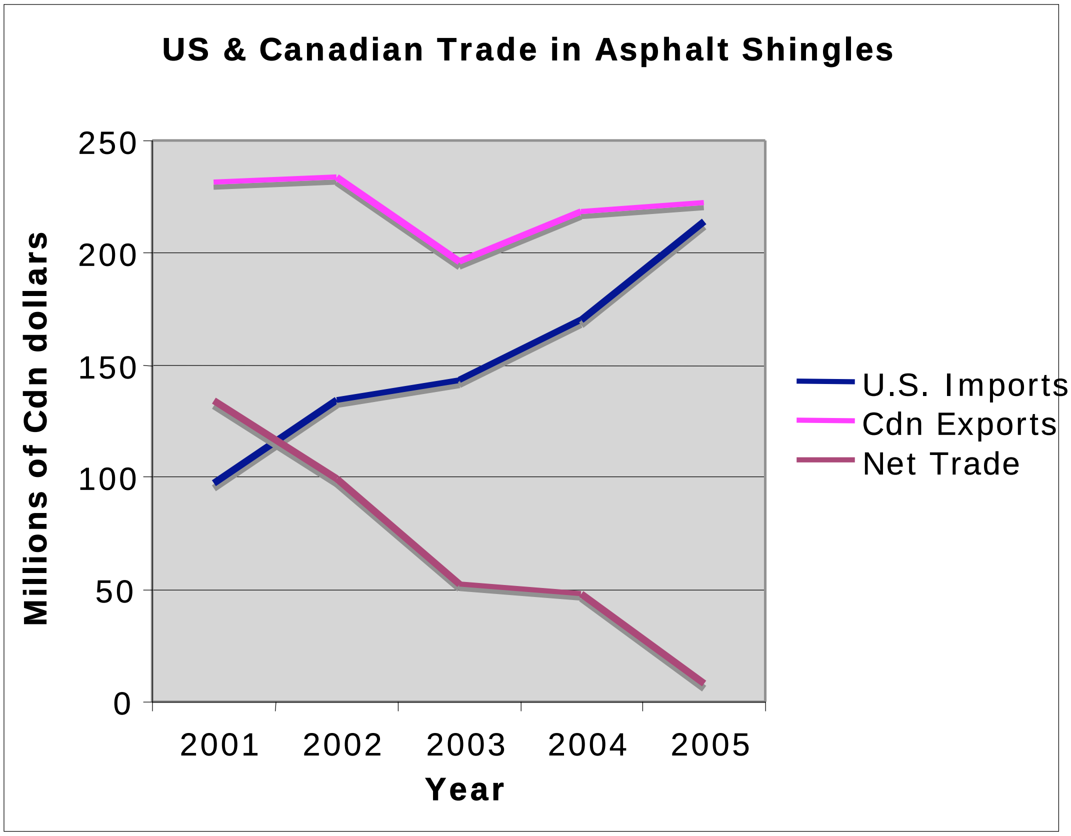
This section focuses on the Canadian residential asphalt shingle exclusively as it is the largest segment of the asphalt roofing industry. Again, much of this section is based on Statistics Canada data augmented with data from CASMA.

In the previous section we noted that asphalt shingles represented the largest segment of the roofing market; imports, however, were not included in the analysis. Table 4 again shows Canadian production, domestic shipments and exports, but also includes U.S. imports into Canada, thus providing a more complete picture of overall Canadian consumption of asphalt shingles. Canadian exports have remained relatively constant, while U.S. imports of asphalt shingles have steadily increased on a volume basis. Prior to the signing of the North American Free Trade Agreement, the U.S. didn’t ship shingles to Canada. And while Canada is now a net importer of asphalt shingles in terms of volume, Canada still enjoys a small trade surplus in asphalt shingles with the U.S. on a monetary basis (Figure 1). CASMA has interpreted this volume/value difference to mean that Canada is importing lower value (i.e., lower durability) asphalt shingles from the U.S. This may have implications for the industry in the longer-term as these U.S. lower durability shingles will need to be replaced sooner.

Table 4 Canadian Asphalt Shingle Production, Shipments, Exports/Imports & Apparent Consumption

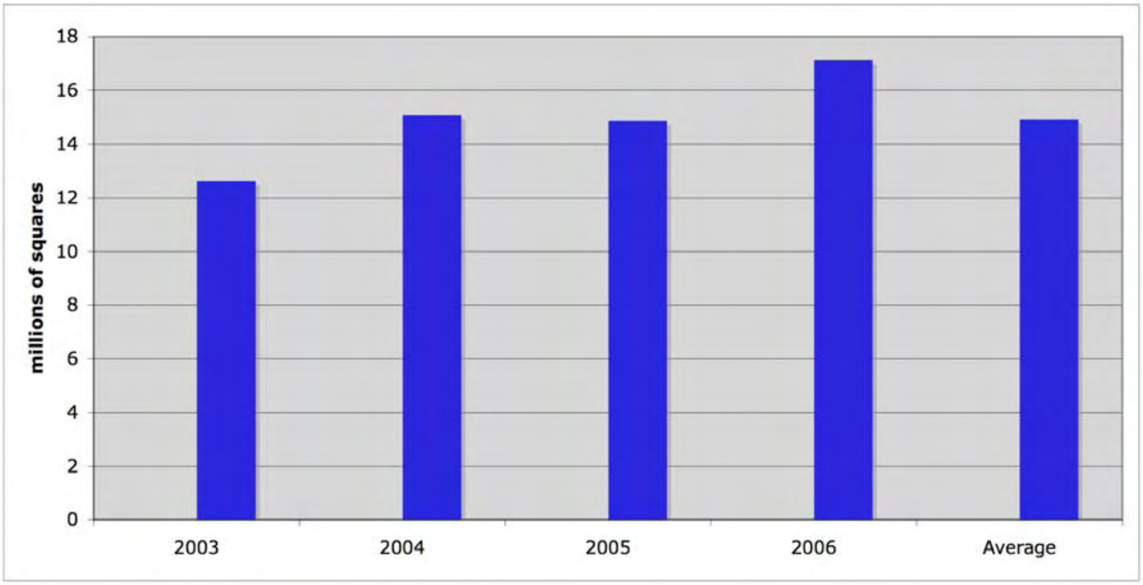
millions of metric bundles	**2003**	**2004**	**2005**	**2006**	**4-yr Average**
Cdn Production	42	44	40	49	44
Domestic Shipments	33	39	36	42	37
Cdn Exports	9	9	9	9	9
Cdn (US) Imports	6	8	10	11	9
Cdn Consumption	39	47	46	53	46

Figure 1 U.S. & Canadian Trade in Asphalt Shingle



Over the last four years, Canadian asphalt shingle consumption has increased steadily and mirrored the growth in new housing starts. On average, 46 million metric bundles, or approximately 15 million squares of asphalt shingle roofing, have been installed in Canada (see Figure 2). Regionally, Central Canada (Ontario and Quebec), Alberta plus British Columbia, and the combined Prairie and Maritime provinces have accounted for 65%, 20% and 15%, respectively, of asphalt shingle consumption in Canada over the last four years.

Figure 2 Canadian Asphalt Shingle Consumption (in million of roofing squares)



2.3 Estimated Canadian Asphalt Shingle Waste

CASMA estimates that over the long term, re-roofing accounts for 80% of Canadian asphalt shingle demand annually. This estimate is similar to those of other literature sources. ARMA estimates that re-roofing accounts for 80 to 85% of annual asphalt shingle use in the U.S. Annually, roof installation generates an estimated seven to 10 million tons (six to nine million metric tonnes) of shingle tear-off waste and installation scrap in the U.S. Table 5 below derives an estimate of annual residential asphalt shingle (re-roofing) tear-off and new construction scrap and related organic felt scrap quantities generated in Canada.

Overall, our analysis of the residential asphalt shingle market suggests that 1.25 million metric tonnes of scrap asphalt shingles and saturated felt are generated in Canada annually.

Table 5 – Annual Generation of Asphalt Shingle and Organic Felt Waste in Canada

	Units	Quantities	Notes
Total An. Roof Squares (mill. of squares)	MMsq	15	
new construction (@ 20% of market)	MMsq	3	
tear-offs (@ 80% of market	MMsq	12	
Mass of shingles per square	m t	0.102	(225 lbs installed)
Mass of felt per square	m t	0.0035	(15 lbs installed)
Total scrap asphalt shingles			
from new construction	m t	4,590	est. @1% of mass
from tear-offs	m t	1,224,000	
Total scrap organic felt			
from new construction	m t	7,350	est. @14% of mass
from tear-offs	m t	21,000	Est. based on 50% of roofs use felt
Grand Total asphalt shingle/felt scrap	m t	1,256,940	

Notes: MMsq - millions of squares, m t – metric tonnes
New construction asphalt shingle scrap estimated by the Athena Institute
New construction organic felt scrap estimated by the Athena Institute

3 The Canadian Industrial, Commercial and Institutional Asphalt Roofing Market

The Canadian industrial, commercial and institutional (ICI) roofing market is typically categorized as a low-slope roofing market. A vast array of roofing products and systems is employed in the low-slope roofing market. There are conventional roofs and protected membrane roofs; there are single and multiple ply roofs; and there are numerous types of membranes and built-up roof systems. The use of roofing asphalt is prominent in three types of roof membranes or systems: traditional 4-ply built-up roofs, 2-ply modified bitumen roofs, and rubberized asphalt roof. Rubberized asphalt garners a small portion of the Canadian ICI roofing market (less than 5%); however, modified bitumen and asphalt built-up roofs combined account for as much as 80% of the ICI low-slope roofing market[4]. The primary national industry association for the ICI sector is the Canadian Roofing Contractors' Association (CRCA) with 320 members representing about 75% of the roofing contractor industry in the country. There are also provincial roofing contractor associations in British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick and Nova Scotia.

The CRCA estimates that the Canadian commercial roofing sector sales approach $1.6 billion on an annual basis. They also estimate that roof replacement accounts for

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[4] Personal correspondence, Mr. Peter Kalinger, Canadian Roofing Contractors' Association, January, 2007. Mr. Kalinger and the CRCA are the primary sources for the information in this section.

approximately 60% of all activity in the sector, with new roof installations accounting for the remaining 40% of the industry's activities. A small portion of the roof replacement segment denotes roof repairs.

3.1.1 ICI Roofing Systems and Asphalt Use[5]

Conventional Roofing Systems

A conventional roofing system is defined as a roof on which the membrane is located above the insulation. In Canada, conventional roofing systems typically require vapour barriers, and can be installed on any type of roof deck. Advantages of conventional systems include reduced loads and protection of the insulation. Disadvantages include the exposure of the membrane to temperature extremes, and the possibility of water or moisture being trapped beneath the membrane. Conventional roofing systems are generally more popular in Canada than protected membrane roof assemblies.

Protected Membrane Roofing Systems

A protected membrane roof assembly (PMRA), or inverted roofing system, is defined as a roof on which the membrane is located below the insulation. In Canada, PMRAs are most often installed on concrete decks, although they are occasionally installed on steel decks. PMRAs typically require a great deal of ballast to reduce the likelihood of flotation or blow-off of the insulation, which is loose-laid above the membrane. In PMRAs, the membrane normally also acts as the vapour barrier. Advantages of PMRAs include protection of the membrane from mechanical damage, traffic, UV light and temperature extremes. Disadvantages of PMRAs include increased cost, increased loads due to ballast, difficulties in performing maintenance, and increased exposure of the membrane and insulation to moisture and water.

PMRAs always utilize extruded polystyrene insulation. Typically, a woven polyethylene filter fabric is utilized above the insulation to provide UV protection for the insulation and to prevent migration of the ballast (commonly aggregate stone). Re-roofing of PMRAs typically involves reuse of a large portion of the insulation and ballast materials.

Asphalt Use

Either roofing grade asphalt or bitumen can be used in built-up roofing (BUR), modified bitumen and rubberized asphalt roofing systems, both as an adhesive and as an integral part of the waterproofing system. Asphalt is typically purchased directly from a refinery and shipped to a processing plant, where it is oxidized. Following oxidation, it is either cooled into cake form at the plant and subsequently delivered to distributors, or delivered while still hot in heated tanker trucks.

The majority of roofing projects in Canada utilize cakes of asphalt, which are delivered to a site on a flatbed truck and re-heated in propane-fired kettles. Heated tanker trucks are utilized on large jobs for both modified bitumen and BUR systems. Currently, tanker trucks serve approximately 15 to 30% of the asphalt market in Toronto, Calgary,

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[5] Much of the material in this section describing roofing/membrane systems and component details comes from an Athena Institute report entitled "Life Cycle Inventory of ICI Roofing Systems: Onsite Construction Effects". Prepared by Morrison Hershfield Ltd., 2001.

Montreal, and Winnipeg. Some energy savings are achieved through the use of tanker trucks due to the delivery of hot (rather than cold) asphalt from the plant.

3.1.2 ICI Roofing Membrane Types

This section briefly describes the various roofing membranes employed in the Canadian ICI market. As previously discussed, single ply (non-asphalt based) membranes, while growing in application in Canada, make up less than 10% of the market; as a result, less effort has been devoted to characterizing these systems in this report.

Single Ply Membranes

PVC Roofing Membranes - PVC (polyvinyl chloride) roof membranes are members of a thermoplastic group of materials. PVC polymers are produced by polymerization of vinyl chloride monomer, a gaseous substance resulting from the reaction of ethylene with oxygen and hydrochloric acid. Additives including plasticizers and stabilizers are utilized to provide a product suitable for roofing applications. Seams in PVC membranes can be welded together with heat or solvent to achieve bonds stronger than the original material.

PVC membranes can be installed as PMRAs or conventional assemblies, and currently make up less than 3% of the Canadian roofing market. The largest distributor in the country is Sarnafil Canada, which supplies the majority of PVC membrane in North America from its plant in the U.S.

TPO Roofing Membranes - The acronym TPO is a chemical industry accepted designation for a family of thermoplastic resins that are created from basic olefinic monomers. The TPO acronym is a true representation of the chemistry in the resin used to make a particular roofing membrane, much as ‘PVC’ represents a family of chlorinated vinyl resins and ‘EPDM’ represents a family of resins also based upon olefinic monomers.

Typically, and for the roofing industry, TPO polymers are blends or alloys of polypropylene plastic or polypropylene and ethylene propylene rubber (EPR) or ethylene propylene diene terpolymer rubber (EPDM). These alloys can be made either by mechanical mixing or by reactor blending using proprietary polymer manufacturing processes. After further mixing with other additives, these polymer alloys are then formed into roofing membranes with a variety of properties.

TPO membranes can be installed as PMRAs or conventional assemblies and currently make up less than 5% of the Canadian roofing market, although increased use is expected in the future. The largest TPO membrane manufacturers serving Canada are Carlisle SynTec and Lexcan/JP Stevens in the U.S.

EPDM Roofing Membranes - EPDM (ethylene-propylene-diene monomer) roof membranes are members of an elastomeric group of materials. EPDM membranes are compounded with polymers and ingredients such as fillers, anti-degradants, processing oils, and processing aids. EPDM contains 30-50% polymer (ethylene-propylene-diene monomer), 20-30% carbon black and 30-50% extender oil, sulfur, accelerator, and anti-oxidant. Sheets are produced by laminating two plies with or without reinforcement. Most EPDM sheets are vulcanized or cured in the factory by heating the compound with sulfur or another cross-linking agent. EPDM membranes can be provided in very long, relatively narrow rolls (2-3m) when they are to be mechanically fastened or fully adhered, or in very large sheets to be used in ballasted or fully adhered systems. Seams in EPDM roofs are created using adhesives either in the field or the factory.

EPDM roofing membranes are typically installed as PMRA or conventional assemblies. EPDM membrane systems in Canada are fully adhered with adhesives, ballasted with smooth stones or concrete pavers, or mechanically fastened with screw and plate systems. Adhered EPDM membranes are usually mechanically fastened with bars at the perimeter and large roof penetrations, and adhered at the remainder of the roof surfaces. Conventional and PMRA loose laid, fully adhered, and mechanically fastened systems are common in Canada.

The largest EPDM membrane manufacturers serving Canada are Carlisle SynTec and Firestone in the U.S.

Multiply Membrane Systems

<u>Built-Up Roofing Membranes</u> - A BUR membrane typically consists of four layers of felt and asphalt and a flood coat of asphalt over the top layer. The felts can be constructed using fiberglass or organic materials. Asphalt is available in several different types which vary by viscosity, although not significantly by composition. Coal tar pitch was once a common component in BUR roofing assemblies, but is now rarely used in Canada. Asphalt is either mopped or poured over the felt layers to provide uniform and complete asphalt coverage of each layer.

BUR membranes currently make up approximately 40% of the Canadian roofing market and are particularly popular in Ontario, Alberta and the Prairies. BUR membranes are typically installed as PMRA or conventional assemblies. All BUR membranes are fully adhered to their substrate, although the insulation above the membrane in PMRAs is ballasted.

Specific components utilized in built-up roofing membrane systems include the following.

- ***Organic Felts:*** no. 15 perforated asphalt felt.
  Unsaturated felt weight = 1.020 kg/m^2 total for four felts.
  Asphalt saturant weight in felts = 1.275 kg/m^2 total for four felts.
  Asphalt (interply and flood coat): 7.0 kg/m^2 total for four felts.

- ***Fiberglass Felts:*** type 4 asphalt saturated glass ply sheet.
  Unsaturated felt weight = 0.372 kg/m^2 total for four felts.
  Asphalt saturant weight in felts = 1.153 kg/m^2 total for four felts.
  Asphalt (interply and flood coat): 7.8 kg/m^2 total for four felts.

- ***Vapour barrier:*** vapour barriers in built-up roofs typically consist of either a 2-ply mopped on felts, or kraft paper. Kraft paper vapour barriers are normally composed of two layers of 30 lb. kraft paper laminated with asphalt and reinforced with glass fiber. Kraft paper weighs about 1.5kg/square. Vapour barriers are typically adhered with asphalt or adhesive.

- ***Vapour barrier adhesive***: if vapour barriers are applied directly to a steel deck, then adhesives are commonly utilized. Typical adhesives are comprised of an engineered cutback asphalt modified to improve elasticity and adhesion. The primary ingredients are asphalt and a solvent base. Other ingredients are proprietary and vary by manufacturer. Approximately 1.8 kg/square of adhesive are used in applications directly over a steel deck, with no appreciable waste.

- ***Primer:*** solvent based asphaltic primer.

In addition to the above, there is typically a gravel cover of 20 kg/m^2 applied for UV protection on conventional roofs. Both IKO and EMCO, Canadian manufacturers of roofing felts (see Section 2.1.1), supply this market.

Modified Bitumen Roofing Membranes are composite sheets consisting of bitumen, modifiers and reinforcements. The term “modified bitumen” encompasses a broad range of materials, with each specific material differing from the others with respect to the modifiers and reinforcements used. Modified bitumen membranes exhibit the thermoplastic quality of being softened by heat. They are typically bonded to substrates by torch application or asphalt.

Reinforcing materials consist of plastic films, polyester mats, glass fibers, felts, or fabrics. The modified bitumen membranes utilized most commonly in Canadian roofing applications, however, include polyester reinforcement mats integral to the material.

Modified bitumen membranes can be separated into two general categories: those utilizing atactic polypropylene (APP) as modifiers, and those utilizing styrene butadiene (SBS) as modifiers. SBS membranes can be applied by torch or asphalt, and are far more typical in Canada. APP membranes are always applied with a propane torch and represent a small portion of the roofing market in Canada.

Modified bitumen membranes currently make up approximately 40% of the Canadian roofing market and are particularly popular in British Columbia and Quebec, but are also used in significant quantities in Ontario. The two largest Canadian manufacturers of modified bitumen membranes are IKO and Soprema.

Modified bitumen roofing membranes typically consist of two layers — a base ply and a finishing (or cap) ply — and are commonly installed as PMRA or conventional assemblies. In PMRAs, modified bitumen membranes are fully adhered to the substrate. In conventional assemblies, modified bitumen membranes are either mechanically fastened with screws and plates, or fully bonded to the substrate. Both types of conventional assemblies, as well as PMRAs, are common in Canada.

Specific components utilized in modified bitumen membrane systems include the following.

- ***Primer:*** solvent based asphaltic primer.
- ***Vapour barrier:*** vapour barriers in modified bitumen membrane roofs typically consist of either a 2-ply mopped on felts, or kraft paper.
- ***Modified bitumen base sheet membrane adhered with* asphalt:** 2.2 mm, fiberglass reinforcement.
- ***Modified bitumen base sheet, torch applied:*** 3 to 4 mm, polyester reinforcement.
- ***Modified bitumen cap sheet, torch applied:*** 4 mm, polyester reinforcement, granule surfaced.

Overall, the total quantity of roofing asphalt used in modified bitumen membranes and their application is similar to that of BUR roof membranes and assemblies.

<u>Hot Applied Rubberized Asphalt Membranes</u> Rubberized asphalt is a flexible, site-applied membrane for use in waterproofing and roofing applications. It consists of proprietary blends of asphalt, mineral fillers, elastomers (natural, synthetic, or a blend of both), virgin or reclaimed oil, and a thermoplastic resin.

Rubberized asphalt is delivered to sites in keg form via truck. It is typically heated on site in large, propane fired kettles and applied by squeegee or trowel. Rubberized asphalt is considered a relatively low cost membrane system, but currently makes up less than 5% of the Canadian roofing market. However, it is gaining popularity in the green roof market place as a PMRA.

The largest manufacturer in Canada is Hydrotech Canada, supplying the majority of rubberized asphalt membrane used in the country.

3.2 Estimated Canadian ICI Sector Asphalt Waste

This section describes the Institute’s calculated asphalt and related roofing scrap for new and replacement BUR and modified bitumen roofing. The process used to estimate the asphalt scrap from this sector is markedly different than that used to derive the asphalt shingle and related scrap for the residential sector. Specifically, the methodology used is as follows:

1. The sector’s total gross sales activity ($1.6 billion) is apportioned between re-roofing and new roofing on the basis of percent activity (60% re-roofing and repairs and 40% new roof construction).
2. Next we apportion the membrane types across the two activities, concentrating on BUR and modified bitumen applications (combined, these two systems are estimated to represent 80% of the overall ICI market).

3. Then, using the average installed cost of BUR and modified bitumen roofing on an area basis, we determine the number of roofing squares for these asphalt products in each segment of the market – re-roofing and new construction.
4. Finally, using the component material breakdown for BUR, we determine the asphalt related scrap flows for the ICI industry sector.

Table 6 below provides the Institute's calculated annual asphalt roofing scrap for the ICI sector as determined using the methodology described above. New asphalt roofing activity contributes a very small portion of the overall calculated waste stream. In total, we have calculated in the order of 330,000 tonnes of asphalt related roofing waste for the sector, with replacement roofing (re-roofing) responsible for 99% of the total waste stream. As calculated, asphalt accounts for 70% of the total waste stream, with felts accounting for another 9%. Aggregate ballast waste at 20% is a considerable portion of the estimated waste stream and is likely on the high side as we did not adjust for the division between conventional and PMRA roofs in the ICI market.

Table 6 ICI Sector Calculated Annual Asphalt Roofing Related Wastes

	Units	Quantities	Source
Total ICI Sector Sales Value	$ millions	1600	P. Kalinger
new construction (@ 40% of market)	$ millions	320	P. Kalinger
replacement (@ 60% of market	$ millions	1280	P. Kalinger
Average cost of BUR/Mod.Bit. Roofs	$/ square	380	P. Kalinger
New construction no. of squares basis	squares	842,105	
Replacement no. of squares basis	squares	3,368,421	
New Construction	m tonnes	0.0035	A. Inst.
unsaturated organic felt use	kg/ square	9.5	A. Inst.
asphalt saturant use in felt	kg/ square	11.8	A. Inst.
asphalt interply and flood coat use	kg/ square	65.0	A. Inst.
asphaltic primer	kg/ square	1.5	A. Inst.
aggregate ballast	kg/ square	185.8	
Replacement (at 90% of new constn)			
unsaturated organic felt lifted	kg/ square	8.5	A. Inst.
asphalt saturant use in felt lifted	kg/ square	10.6	A. Inst.
asphalt interply and flood coat lifted	kg/ square	58.5	A. Inst.
asphaltic primer lifted	kg/ square	1.4	A. Inst.
aggregate ballast (80% reused)	kg/ square	37.16	A. Inst.
Total Scrap in New Construction			Waste factor
unsaturated organic felt use	tonnes	1,117	at 14%
asphalt saturant use in felt	tonnes	1,391	at 14%
asphalt interply and flood coat use	tonnes	547	at 1%
asphaltic primer	tonnes	63	at 5%
aggregate ballast	tonnes	-	
Total	**tonnes**	**3,119**	
Total Scrap from Replacement			**%**
unsaturated organic felt	tonnes	28,724	9%
asphalt saturant in felt	tonnes	35,773	11%
asphalt interply and flood coat	tonnes	197,053	59%
asphaltic primer	tonnes	4,547	1%
aggregate ballast	tonnes	62,585	19%
Total	**tonnes**	**328,682**	99%
Total ICI Sector Asphalt Roofing Scrap	**tonnes**	**331,801**	

Notes:

Average cost of BUR ($3.50/sq.ft.), Mod.Bit ($4.25/sq.ft.) at equal market share = $3.80/ sq.ft.x100=$380/ roofing square

Used a replacement quantity of 90% to account for repair activity

3.3 Total Annual Asphalt Roofing Scrap Production by Component

Table 7 below summarizes the total annual asphalt based roofing scrap available in Canada by primary component. The ICI sector's roofing scrap output is about 25% of that estimated to be produced by the residential sector on a mass basis; however, on a percentage of asphalt basis, the amount of asphalt in the ICI roofing scrap is almost 75% that of the residential market – making it a significant consideration for recycling. Overall, it is estimated that 1.5 million tonnes of asphalt related roofing waste is generated in Canada with the primary components - aggregate, asphalt, and organic felts representing 57%, 35% and 9% by mass, respectively.

Table 7 Annual Residential & ICI Asphalt Based Roofing Scrap by Component

Component	**Residential**		**ICI**		**Total**	
	m tonnes		m tonnes		m tonnes	
Unsaturated org. felt	109,627	9%	29,841	9%	139,468	9%
Asphalt	311,872	25%	239,384	72%	551,256	35%
Aggregate/Granules	835,441	66%	62,585	19%	898,026	57%
Total	1,256,940	100%	331,810	100%	1,588,750	100%

4 Enhanced Asphalt Roofing Recovery

This section describes the various end-uses, processing steps and regulations covering the recovery and recycling of asphalt roofing in North America. Much of this section arose from an extensive web and literature review and discussions with various parties familiar with asphalt material recovery and use. Considerably more information was found regarding asphalt shingle recycling (www.ShingleRecycling.org) than ICI asphalt roofing, but given their similarities, much of what is applicable to asphalt shingles is also applicable to ICI asphalt wastes.

4.1 End-uses for Asphalt Roofing Waste

Several potential reuse and recycling markets exist for Residential and ICI asphalt scrap. The benefits of recycling asphalt roofing products include conservation of landfill space and resources, and reduced costs of disposal and product production as compared to typical landfilling or virgin product production costs. Some of the obvious negatives associated with establishing an asphalt recycling facility are uncertain capital costs, potential difficulty obtaining various permit licenses, a highly variable material supply and sources, and undeveloped and/or under-developed markets.

4.1.1 Hot-Mix Asphalt (HMA)

This is the largest current market for recycled asphalt shingles (RAS) in the U.S. 16 states allow asphalt shingles to be incorporated into hot-mix asphalt (HMA) (see Figure 3 below), with other states likely to follow. A number of laboratory and field experiments in North America have been performed regarding the feasibility of recycling asphalt shingles. Many of these studies have been carried out by US state transportation or environmental departments, and most of these projects have culminated in specifications from state Departments of Transportation (DOT) allowing manufacturer or tear-off asphalt shingle scrap use in HMA mix designs.

Most specifications for RAS use in HMA require that the mix only include manufacturers' scrap (pre-consumer) or tear-off (post-consumer) material. Most specifications will not allow a mixture of the two. Many specifications only specify the use of manufacturers' scrap, as it does not contain the deleterious material (metal, glass, paper, etc.) found in tear-off loads. Pre-consumer asphalt shingle manufacturers' scrap is currently being used in hot-mix asphalt in Ontario. Lafarge is the leader in this area.

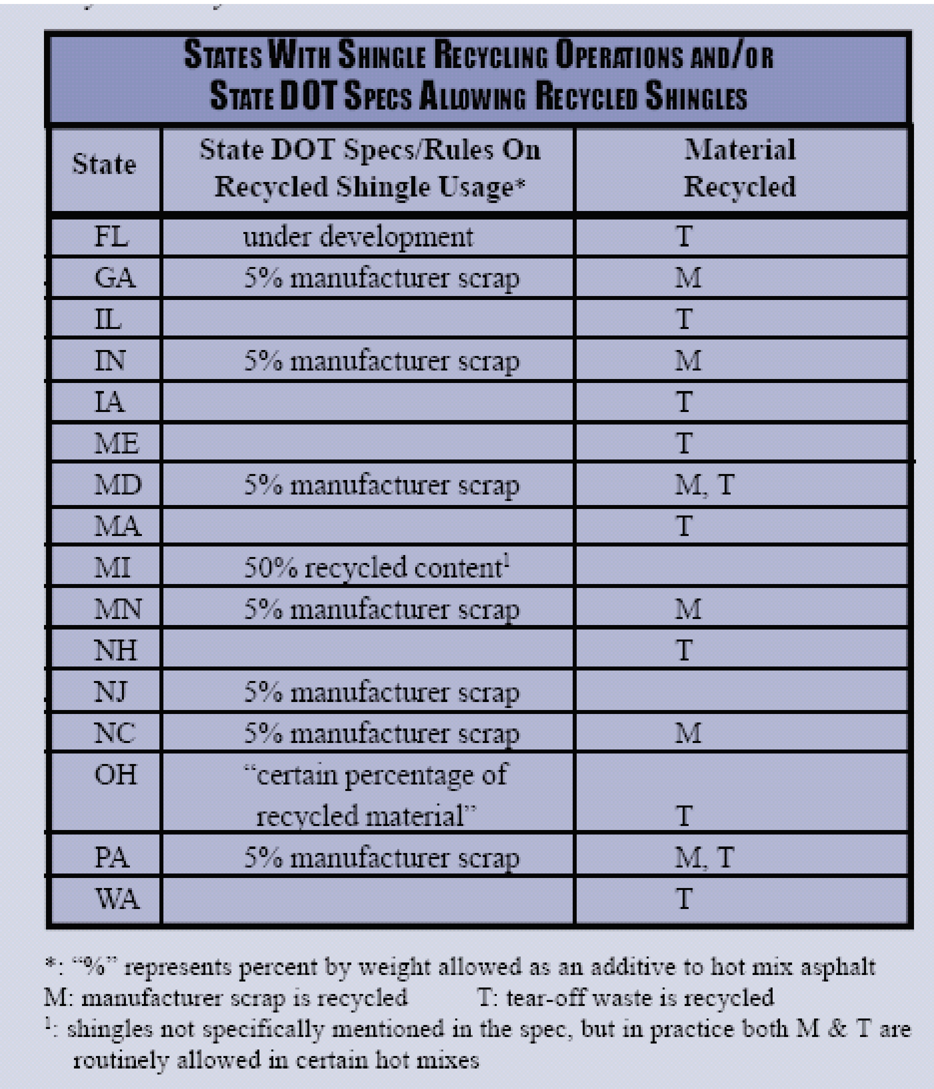
Hot-mix pavement design formulas usually contain between 5 and 7% bitumen. These formulations are based on two factors: climate, i.e., precipitation and hot/cold temperature extremes; and traffic conditions, including types of vehicles and volume/types of traffic, e.g., rush hour, stop and go, or highway. Because climate and pavement specifications vary from state to state, state DOTs have needed to independently test the effect that adding recycled shingles has on a pavement's performance. Test pavements with batches containing a maximum of 5% shingles by weight of mixture have performed at least as well as traditional pavement (both manufacturers' scrap and tear-off were tested); however, with current technology, if shingles are added at a higher percentage, performance may begin to suffer due to the harder asphalt found in shingles. Employing a softer grade of asphalt cement in the HMA mix design may allow greater quantities of asphalt shingles to be used. This is the subject of a number of pending research projects in this field.

In 2005, the American Association of State Highway and Transportation Officials (AASHTO) adopted a standard materials specification (MP 15) for utilizing both manufacturers' and tear-off asphalt shingle scrap in HMA. This national specification enables HMA producers to design the appropriate mix of RAS in asphalt to meet the specifications of state and local transportation agencies. Some of the specifications detailed requirements include the following:

- the final RAS product must be sized and screened such that 100% passes the ½ inch sieve screen;
- gradation must meet the requirements of the mix design;
- deleterious material must not exceed a maximum of 0.50% by weight, cumulative total (i.e., combination of all metal, glass, paper, rubber, wood, nails, plastic, soil, brick, tars and other contaminating substances); and
- the final RAS product must meet the asbestos level established by the state or U.S. EPA.

AASHTO also adopted a recommended practice (PP 53) as a companion to the standard specification.

Figure 3. U.S. States Allowing (RAS) in HMA



STATES WITH SHINGLE RECYCLING OPERATIONS AND/OR STATE DOT SPECS ALLOWING RECYCLED SHINGLES

State	State DOT Specs/Rules On Recycled Shingle Usage*	Material Recycled
FL	under development	T
GA	5% manufacturer scrap	M
IL		T
IN	5% manufacturer scrap	M
IA		T
ME		T
MD	5% manufacturer scrap	M, T
MA		T
MI	50% recycled content[1]	
MN	5% manufacturer scrap	M
NH		T
NJ	5% manufacturer scrap	
NC	5% manufacturer scrap	M
OH	"certain percentage of recycled material"	T
PA	5% manufacturer scrap	M, T
WA		T

*: "%" represents percent by weight allowed as an additive to hot mix asphalt

M: manufacturer scrap is recycled T: tear-off waste is recycled

[1]: shingles not specifically mentioned in the spec, but in practice both M & T are routinely allowed in certain hot mixes

Source: U.S. Environmental Protection Agency (EPA)
www.epa.gov/epaoswer/non-hw/debris-new/pubs/roof_br.pdf

4.1.2 Cold Patch

The use of RAS as cold patch is a practice that has been employed for years. It has been used in New Jersey, Washington state, and California, as well as in the city of Chicago. Presently, Gardner Asphalt Corporation of Tampa, FL supplies Home Depot with an RAS cold patch product.

According to field tests, RAS cold patch behaves like a "high-performance" patch, outlasting HMA and traditional cold mixes. The fiberglass and/or cellulose fibers in the shingles apparently add to the structural integrity of the patch.

Although the initial cost of RAS cold patch is usually higher than HMA and traditional cold patch, the overall cost may be lower due to longer life and decreased maintenance costs. When compared to other high performance patches, the RAS cold patch usually costs less.

RAS cold patch is easier to use than traditional patches for the following reasons:

- lighter weight — it has a lower weight-to-volume ratio, so it is easier to handle;
- no equipment needed — just fill the crack or pothole and tamp down with a shovel or drive over it; and
- time flexibility – RAS cold patch doesn't harden as quickly as HMA, so there's no hurry to use it; after applying, traffic can be allowed over the area immediately.

4.1.3 Dust Control on Rural Roads

Recycled asphalt shingles may be ground and mixed into the gravel used to cover rural, unpaved roads.

4.1.4 Temporary Roads or Driveways

RAS has been used in temporary roads, driveways, and parking lot surfaces. RAS is typically ground to ¼-inch and passed under a magnetic separator in order to remove all nails. The processed shingles are spread and compacted for an easily installed surface. In Altus, OK, RAS was mixed with reclaimed asphalt pavement (RAP) to create a parking lot surface.

4.1.5 Aggregate Base

Little research has been conducted into this market, but recycled shingles have been used as part of the sub-base in road construction. Processed shingles may be blended with RAP and concrete. It is suspected that the addition of RAS may improve the compaction of the sub-base.

4.1.6 New Roofing Shingles

A report prepared for the U.S. Department of Energy in 1984 indicated that the addition of up to 20% of recycled shingles did not affect the production of new shingles. Significant energy savings were achieved by using RAS. Others have also looked into closed loop recycling of asphalt shingles and found problems persisted in reprocessing shingles to conform to feedstock requirements or locating/devising technologies that could maintain product performance specifications. The majority of asphalt shingle manufacturers' scrap is finding a use in paving products, rather than the plant. We are unaware of any facility producing new shingles for either manufacturer's scrap or tear-off material on a commercial basis.

4.1.7 Fuel

Energy recovered from waste shingle feedstocks is an established market in Europe. Only recently has the concept been applied in the U.S. to produce No. 6 fuel oil. It is very limited, however, because of concerns over air pollution. The Lafarge cement plant in

Brookfield, NS is using a “flaked” asphalt shingle scrap as a fuel source in its cement kiln (see case study section 4.3.4).

4.2 Asphalt Roofing Scrap Processing

Because scrap from shingle manufacturers comes from a known source and is not contaminated with other materials, it is usually preferred. But, as discussed above, post-consumer scrap shingles (tear-offs) can also be recycled, provided that materials such as paper and nails are removed. Some markets allow a greater amount of manufacturers’ scrap to be used as compared to post-consumer material.

When processing tear-off shingles for recycling, the shingles must be separated from other components such as wood, metal and paper. This can be performed at the source (job-site) or at a processing location. Debris must be removed to prevent equipment damage during size reduction. There is no standard processing equipment to accomplish this task; as a result, it is very labour intensive. Possible contaminants may include the following.

- Metals, which can be removed by a rotating magnet.
- Wood, which sometimes accompanies shingles when the plywood is also replaced in a re-roof job, and is the biggest problem: unlike nails, wood cannot be extracted by magnets, and unlike plastic, it doesn’t melt during the asphalt mixing process. Wood can be removed by hand, or floated off in a water flotation unit.

Waste shingles are typically ground using a horizontal mill, although tub grinders have been used in some applications. The ground shingles are usually screened to achieve a uniform product size (depending on the market). The ground shingles are passed under a magnet or magnets to remove nails. Below, each step in the processing of asphalt shingles for inclusion in HMA is briefly described. Similar processing steps would be conducted for a number of the other possible end-uses discussed previously.

Shredding

Roofing shingle scrap used in asphalt paving mixes is typically shredded into pieces approximately 13 mm (½-inch) in size and smaller, using a shingle shredding machine that consists of a rotary shredder and/or a high-speed hammermill.

Screening

Shredded shingles are typically discharged from the shredder or hammermill, screened to the desired gradation, and stockpiled. Experience indicates that the size of the processed pieces should be no larger than approximately 13 mm (½-inch) to ensure uniform incorporation of the roofing shingle scrap into the hot-mix asphalt. Scrap shingle greater than 13 mm (½-inch) in size does not readily disperse, functioning much like aggregate. Particles sized too small can release the fibres, which may act as a filler substitute.

Blending
Processed roofing shingle material can re-solidify during stockpiling, necessitating reprocessing and re-screening prior to introduction to the hot-mix plant. To mitigate this problem, processed roofing shingle scrap may be blended with a carrier material such as sand or recycled asphalt to prevent the particles from sticking together.

Watering
To keep the roofing shingle material from agglomerating during processing, it is usually passed through the shredding equipment only once, or kept cool by watering at the hammermill. Watering of the processed shingle scrap may also be required to conform to environmental regulations concerning dust generation. However, the application of water is not desirable, since the processed material naturally becomes quite wet and must be dried prior to introduction into hot-mix asphalt.

Grinding
To prepare shingles for use in new products, the shingles must be ground to a specified size. Grinding may be easier in the winter when the asphalt is more brittle. If the shingles begin to stick together in hot weather, or from the heat of the equipment, the material may be sprayed with water or have sand or gravel blended into the mix to reduce agglomeration of the material.

Sizing
Depending on the equipment used, primary grinding may yield 2-inch- or 3-inch-minus size pieces. Secondary grinding may be required to make smaller pieces if required; for example, aggregate base may require ¾-inch-minus, and asphalt pavement may require ½-inch-minus or ¼-inch-minus.

Sieving/Screening
Depending on the use, the shingles may have to be sieved or screened after grinding, to conform to grading requirements. The process removes contaminants from the ground shingles.

Equipment
Recycling of shingles typically requires modification of standard grinding, screening, and dust control equipment in order to process shingle waste material for the desired end-use products. Most processors improvise by modifying simple equipment. A hammermill will grind shingles, though it works best with softer aggregates, such as limestone, as opposed to granite granules. Recent advances in equipment design have overcome previous problems with blade wear and dust control. Secondary grinders are being used to process a variety of materials, including asphalt shingles.

Some machines have even been designed to specifically process roofing and other construction wastes. A Canadian company, Hammel Canada, produces and sells shredders and screens designed to handle shingles.

4.2.1 Processing Plant Regulations

Neither the Canadian nor U.S. federal government has a specific regulation for asphalt shingle recycling. Therefore, facilities that recycle asphalt shingles must follow appropriate provincial/state and local municipal regulations and, in some cases, obtain the necessary permits or licenses. Each province/state inevitably has different requirements.

The types of requirements for recycling asphalt shingles vary. A permit to operate a processing facility may be required in some areas, and environmental testing may be required in other areas. In addition, depending on the particulate emissions from the recycling process, an air permit may be required at the facility. The single biggest issue that has been raised with respect to asphalt shingle recycling is asbestos. The asbestos content of asphalt shingles has fallen from 0.02% in 1963 to zero today. The vast majority of tests conducted on asphalt shingles to be recycled have found no asbestos. However, other asphalt roofing products, such as roll-roofing, adhesives, paints or water proofing compounds, may contain asbestos. To strike a balance between the protection of worker health and the encouragement of recycling, several states have worked with recyclers to conduct initial testing on their waste stream to demonstrate the safety of their operation. But ongoing testing remains a ‘cost of doing business’ for some asphalt shingle recycling facilities.

4.3 Asphalt Roofing Recycling Case Studies

This section summarizes four case studies on the use of scrap asphalt roofing products in Canada and the U.S. These studies speak to the various market forces, processes and the regulatory environment surrounding asphalt roof product recycling.

4.3.1 Recycled Asphalt Shingles Used in Lunenburg Trail Construction

A pilot project was initiated by the Municipality of the District of Lunenburg, NS, to investigate the use of discarded asphalt shingles as a potential nature trail surfacing material. The project aims at significantly reducing the quantity of shingles sent to landfill[6]. Project sponsors are a mix of federal, provincial, and municipal governments, as well as corporate entities.

In October 2006, three sections of rail-trail were covered (500 metres per section) with a recycled asphalt shingle aggregate mix, which creates a dense, stable surface resistant to wear and tear, yet easily graded and repaired if necessary. This project is the first of its kind for the municipality and will continue for a 12-month period. Careful monitoring and testing is being carried out by a private environmental monitoring company. The testing program was devised to confirm that there is no significant impact to surface water quality from runoff from the trail surfacing product. Testing will take place at

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[6] Current landfill fee in Nova Scotia for asphalt shingle waste is $0.75/20 lbs. ($83/tonne) after the first 1000 lbs., which is accepted free of charge. (Personal Correspondence, Laura Barkhouse, Municipality of the District of Lunenburg).

three-month intervals. Due to the project's newness, there is no confirmed data regarding environmental or economical costs/benefits as of yet, but positive results are anticipated.

Regulations/Requirements
Nova Scotia does not currently have any standards for the use of asphalt shingles in road surface construction. There are, however, regulations regarding solid waste management. Used asphalt shingles are considered waste under the Solid Waste Management Resources Regulations. In order to dispose of solid waste (i.e., by spreading shingles on the ground), a permit is necessary. However, if asphalt shingles are processed as a feedstock for another product, then their use is not considered disposal and is not subject to the Environment Act and Regulations. The challenge in the Lunenburg project came in determining whether the shingles were waste, or a product. The Nova Scotia Department of Environment and Labour (DOEL) concluded that if the trail surface were to be designed by a Professional Engineer, who would also supervise its construction, the asphalt shingles would be considered a feedstock for a new product, and the practice would not require approval from the DOEL.

Processing Procedure
Tear-off shingles are selected as they arrive at the recycling centre. In this way, the workers can ensure that the shingles used are not contaminated. The shingles are accumulated and put through a round tub grinder, producing a 2-inch-minus material, then pass over a magnet, which removes any nails or other metals. During this process, water may be added to reduce dust.

The shingles are then put through a trommel screen with ½-inch x ½-inch mesh openings. The finished product goes over a magnet again. The final product continues on to a clean stockpile and is set for mixing with gravel. Any oversized material is removed by visual inspection and then reground and screened again.

Shingles are sized to meet requirements, then loaders are used to mix and roll the material together with aggregate. Two different mixes for trail use areas are being tested in this project:

1. 50% ½-inch-minus shingles and 50% ¾-inch-minus gravel
2. 75% ½-inch-minus shingles and 25% ¾-inch minus gravel

The finished product is either stockpiled or trucked out immediately for use.

4.3.2 Roofing Shingles in Asphalt Based Paving Products

In 1988, a U.S. company, ReClaim, produced a number of asphalt based paving products at two New Jersey plants: one in Kearny, the other in Camden. The plants reclaimed and reused non-hazardous, non-toxic asphalt roofing scrap to produce paving material, pothole patch material and hot-mix asphalt modifier. For quite some time, ReClaim was the only state certified recycler of asphalt roofing material in the USA.

New Jersey's state recycling program required roofers and demolition waste haulers to deliver a portion of their demolition waste to certified recycling facilities. In September

1989, ReClaim's Kearny plant was the first facility to be certified as a "waste-diversion recipient" by the New Jersey Department of Environmental Protection. Local governments therefore awarded "diversion credit" to haulers who took recovered material to ReClaim as part of the State's mandatory recycling program. High tipping fees (at the time, $115 per ton at Kearny-area landfills) provided further incentive for haulers to take material to ReClaim.

ReClaim processed 300 tons per day of clean roofing scrap at its Kearny facility. The feedstock was a mixture of various roofing materials. ReClaim estimated that approximately 60% of the material arriving at the plant was post-consumer commercial built-up roofing, and 38% was post-consumer asphalt shingles. The remaining 2% was scrap asphalt shingles from a nearby shingle manufacturer. The plant accepted material on site, but also maintained 20 drop sites within New Jersey.

In August 1992, ReClaim began adding quarried aggregate to the reduced roofing material in production of its pothole patch. Because the asphalt roofing was processed before it was combined with the aggregate, the new product increased production capacity of the facility without altering the parameters of the plant.

The production process at ReClaim's Kearny facility was based on simple material reduction and was accomplished mainly with two mechanical volume reduction machines (MVRM) modified to withstand the extreme wear caused by abrasive roofing scrap. ReClaim succeeded with this process where other roofing asphalt processors failed because of the durable and cost-effective MVRMs which they developed in-house. As roofers unloaded material onto a receiving pile at the facility, workers inspected it for contaminants. A bucket loader mixed the pile and loaded it into a modified MVRM that reduced the material to a less than 6-inch size. This feedstock then ran through a second MVRM before it was screened to specified size, depending upon the end product. Oversized pieces were returned to the MVRM, and ferrous metals (i.e., nails and wire) were magnetically removed. At the time, accepting the materials to produce one ton of Econo-Pav® brought ReClaim $65 ($64 per ton tipping fee and $1 per ton) in revenue. A five gallon bucket of Repave® sold for $7.75 wholesale.

Both the Kearny and Camden plants, although seemingly quite successful in their initial phases, are no longer operational. The company's head office and facility located in Tampa, FL has also ceased operation.

Gardner Asphalt Project

Approximately 25 years ago, Gardner Asphalt Corporation began a project, working together with ReClaim, to recycle asphalt shingles for use as a cold patch product. At the time, Gardner purchased separated, ground up, used shingles (from BUR) from ReClaim's various collection sites (New York, Newark, and surrounding areas). Gardner now purchases separated, ground shingles from local processing plants for 10¢/lb. ($220/m tonne). Asphalt is extracted from the ground shingles using solvents, mixed with additives, then aggregate, creating a cold patch material for potholes, etc. Gardner currently has three plants where this takes place: Tampa, Chicago and Houston. Gardner sells the cold patch product through Home Depot in the U.S.

4.3.3 Asphalt Shingle Recycling in Massachusetts

GreenGoat, a non-profit efficiency consultant based in Somerville, MA, conducted a case study[7], sponsored by Home Depot, which examined the generation rates and markets for post-consumer asphalt shingles in Massachusetts. The project was undertaken as part of an ongoing effort to discover and develop markets for construction and demolition debris.

The study concluded that the most promising application of post-consumer shingles in Massachusetts is road surface and base. Massachusetts Highway resurfaces enough roads to potentially buy 27,551 tons of shingles per year, assuming it would change its regulations to allow post-consumer content. If municipal roadwork were added to this, it would bring the total potential market to 82,653 tons per year.

The study found several factors influencing the rate of recycling (particularly for pavement).

> **Performance**. The binding attribute of shingles is not diminished with time, although the elasticity is (a factor which is important for pavement). “Recipe adjustments” have been made to accommodate the effects of aging. In order for Massachusetts Highways to accept shingle into pavement materials, additional testing of the “recipes” used for surface and base would need to be done. In addition, added brittleness, further loss of elasticity and lower stone dust content as a result of exposure to the Massachusetts weather are factors.
>
> **Purchasing practices**. Specifications s allow for *post-industrial* content in pavement (although none is being used), and there is no provision for *post-consumer* content in Massachusetts highways.
>
> **Predictable supply of feedstock**. Established shingle recyclers are able to adjust volume to supply their markets with what they need. Many aggregate companies also produce pavement and contract, which helps leverage cost savings on state paving jobs. Shingle recycling is increasing; as a result, shingle manufacturers will be more confident in investing money in the development of better recipes for post-consumer use of their shingles.
>
> **Method of de-installing material**. Source separation is easy, but change will come slowly because the labour is traditional; labourers have to be convinced to tarp an area to minimize yard waste and to prevent recyclable materials from going into the load.

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[7] A. Bauman. “Asphalt Shingle Recycling in Massachusetts,” March 15, 2005. The above summarized paper is available at thegoat@greengoat.org.

Complexity of the material. Shingles are composed of asphalt, stone dust, organic felt or fibreglass backing, and adhesive. Sorting them into product types so that they can be used as feedstock for new shingles is not cost effective. This is significant for manufacturers accepting the material.

Purity of product. Shingle recycling is a “young” recycling group and in order to accept post-consumer material, a producer has to be confident that the load taken in meets market specifications. In the Massachusetts government, the perception remains that the use recycled material is riddled with quality issues.

Availability of markets. Recycling technology is ready, but demand is low. Markets for shingles in Massachusetts are hot-mix asphalt, aggregate road base, cold patch, and erosion control; however, shingles are currently only used in private paving jobs. Simple education and marketing are needed to create markets for recycled shingles.

Price of virgin materials. Shingles are petroleum-based, and transportation of heavy virgin materials burns gas. As petroleum prices rise, the value of post-consumer feedstock becomes more attractive.

Regulatory Incentives. Massachusetts is planning to ban asphalt shingles from landfills once markets can handle at least 75% of the current waste. At the same time, the State is encouraging markets for recyclable materials such as asphalt shingles with incentives such as grants.

4.3.4 C&D Recycling Ltd., Nova Scotia

In 1995, Nova Scotia passed the Nova Scotia Environment Act and the province formally adopted a target of 50% diversion of solid waste from disposal by the year 2000. The province succeeded in achieving that goal and continues in its efforts.

Halifax Regional Municipality has since passed a bylaw that requires 75% of waste to be diverted from landfill. A second bylaw was passed which does not allow movement of waste outside of the municipality. The Municipality also created an incentive to divert waste from landfills by paying between $18 and $22 per tonne for each tonne diverted.

Used asphalt shingles have been utilized for a number of years in Nova Scotia as landfill coverings. Used, ground shingles (ground onsite), have also been used for amendment to roads. With the new bylaws in place, Canadian recycler Halifax C& D Recycling Ltd. developed a process in 2005 to separate sand and asphalt from the paper portion of shingles. The resulting product, ‘Asphalt Grit’, is used by Ocean Contractors in Dartmouth, NS, in hot-mix asphalt paving.

The Asphalt Grit replaces 2 to 3% of the new liquids in hot-mix (asphalt cement sold for approximately $500/tonne last summer) used in paving product, and it also replaces some of the natural sand used in the asphalt mix. Lab tests of the Asphalt Grit show no difference in flow or bonding, or in stability of the final product, when compared to a virgin mix. This can be attributed to the fact that 75% of the paper in the shingle is removed. Field tests showed the same positive results: there was no difference between Asphalt Grit (replacing 1 and 2% of liquid in hot-mix), and regular asphalt cement.

Once the sand portion has been removed from the asphalt shingle, a second product, ‘Asphalt Flake’, is produced. This flake (fibre paper coated with asphalt) is being used as fuel in place of coal at Lafarge’s cement plant in Brookfield, NS. The flake is replacing 10% coal fuel per hour. Approximately 20 to 30 tonnes of Asphalt Flake are being blown into the kiln per day. Tests have shown the use of flake has reduced emissions.

According to Halifax C&D, to their knowledge, neither process has been tried anywhere else in North America.

The Resource Recovery Fund Board (RRFB) of Nova Scotia — Nova Scotia’s business development program — is a provincial initiative that provides funding for waste diversion. Eligible applicants include individuals, businesses and universities undertaking projects that support the goals of the Nova Scotia Waste Resource Management Strategy. Funding is divided into three categories: value-added manufacturing, which provides funding for the manufacture of products or services that recover materials from the waste stream; research and development funding, for research studies or pilot projects that divert waste materials or add value to materials diverted from the waste stream; and special projects funding, for initiatives that divert materials recovered from the waste stream. Halifax C&D received approximately $67,000 from the RRFB grant, to be used for equipment.

5 Enhanced Recovery Market Drivers

This section describes prevailing economic and environmental factors influencing current and future recycling of asphalt roofing products. The Greater Toronto Area (GTA) is highlighted as a location where various market and regulatory forces are aligning that may spur on asphalt roofing recycling.

5.1 Economic Drivers for Asphalt Roofing Recycling

This section highlights the price of bitumen, as used in hot-mix asphalt concrete, escalating fuel prices, and landfill tipping fees as the primary economic drivers influencing the development of an extensive asphalt roofing recycling industry.

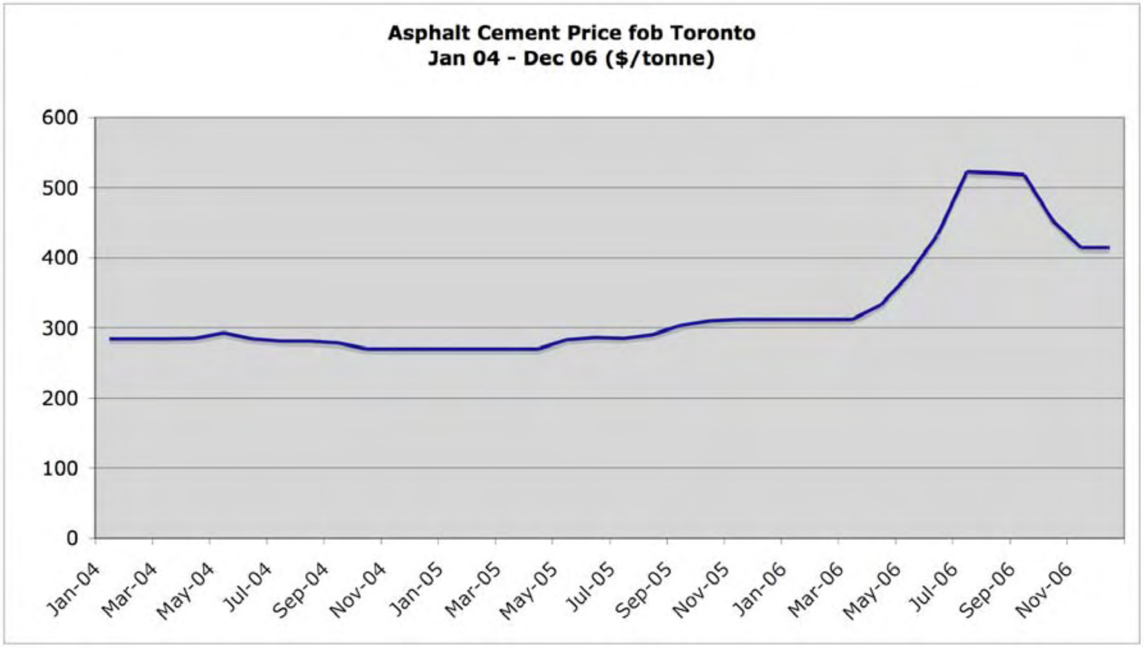
5.1.1 Hot-Mix Asphalt Production, Asphalt Cement & Fuel Prices

It is estimated that there are just over 500 hot-mix asphalt plants across the country producing in the order of 30 to 31 million tonnes annually. The province of Ontario has the greatest concentration of plants (28%) and produces about 40% of all hot-mix asphalt concrete in the country. In Canada, most asphalt production plants are over 30 years old and are predominately batch plants producing between180 and 240 tonnes per hour (tph)[8]. Typically, hot-mix asphalt concrete contains a mixture of 5% asphalt cement and 95% aggregate. It is therefore estimated that the Canadian hot-mix asphalt industry consumes in the order of 1.6 million tonnes of asphalt cement and 29.5 million tonnes of aggregate annually. The total combined scrap generated by the Canadian residential and ICI asphalt roofing industry is estimated at about 1.5 million tonnes in total, of which asphalt makes up about one-third of the total scrap, with the remaining components being aggregate and felts, which are also materials usable by the HMA industry.

Replacing 5% of the virgin raw materials in the Canadian HMA industry with asphalt roofing product scrap would result in the use of 1.6 million tonnes of asphalt roofing product scrap annually, i.e., all roofing asphalt scrap produced in Canada in a single year. Further, it is estimated that by making this substitution the HMA industry would avoid generating 90,000 tonnes[9] of greenhouse gases. Obviously, the HMA sector is a key potential market for asphalt based roofing scrap.

Due to supply constraints and growing demand for HMA, prices for asphalt cement have skyrocketed in recent months (see Figure 4 below).

Figure 4 Recent Asphalt Cement Prices, FOB Toronto



Source: Ministry of Transportation Ontario (PG Grade 58-28 or equivalent)

Although most petroleum and natural gas products have seen remarkable price increases, asphalt cement prices have been relatively stable. In March 2003, asphalt cement prices spiked to an all time high of $349.75/tonne (MTO Asphalt Price Index April 2003) when

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[8] Source: "An Energy Use Benchmarking Study and Reduction Guide for Canadian Road Builders", prepared for The Canadian Construction Association (CCA) by the Athena Institute, 2004.

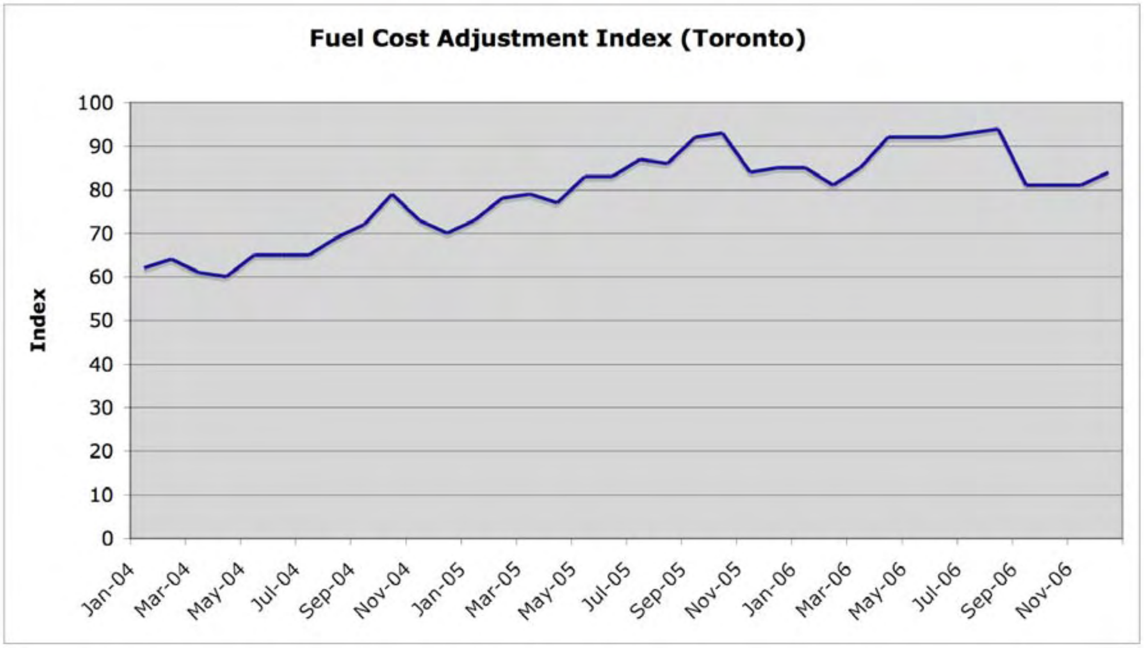
[9] Athena Institute estimate calculated at 59 kg CO_2 equivalent per tonne of asphalt concrete

crude prices rose by 90% year over year to what seems now a very modest $37.83 per barrel. In the intervening three-year period, asphalt cement prices have fallen back to as low as $270/tonne in November 2004, finishing at the end of the last season at $312.20/tonne.

Perhaps the most significant reason for this increase is the relatively large increase in gasoline, diesel fuel (see Figure 5 below) and home heating oil prices, which makes conversion of the heavy bottom of the barrel feed stock, where asphalt cement resides, economically feasible. U.S and Canadian refineries have invested hundreds of millions of dollars in the last few years in cokers for this type of conversion. At the same time, the closure of Petro-Canada's Oakville refinery has left Imperial Oil's Nanticoke refinery as the only provincial producer and increased the province's reliance on outside suppliers.

The Ontario Hot Mix Asphalt Producers Association (OHMAPA) expects this recent increase in the asphalt cement price to remain in place. While asphalt cement prices will continue to fluctuate, it is unlikely in the long term that they will find their way back to $300/tonne. At a cost of $400/tonne for asphalt cement, the asphalt cement cost per tonne of HMA produced (at 5% asphalt cement content, about 50 kg) would be $20.00 per tonne. On the basis of a 5% displacement of asphalt cement with asphalt roofing scrap, the inferred value of roofing scrap is $125/tonne. With Toronto construction and demolition waste tipping fees at about $85/tonne[10], incorporating asphalt roofing scrap in HMA looks attractive and warrants more investigation.

Figure 5 – MTO Diesel Fuel Cost Adjustment Index[11] for Toronto



Source: Ministry of Transportation Ontario

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[10] Personal correspondence – Avenue Road Roofing (January 2007)

[11] The Fuel Cost Adjustment Index is based on the price, including taxes, FOB Toronto area terminals for low sulphur diesel – MTO.

5.1.2 Tipping Fees

The current construction and demolition waste regulatory situation varies significantly across North America. The reasons for such different treatment of construction and demolition waste appear to be, among other things, interplay between landfill availability, economics of diversion/recycling/reuse, concentration of population, and local/regional attitudes about waste and recycling. Such differences are manifested in the types of programs that are promoted or enforced in a particular city or region.

Although many cities and regions do not have specific construction and demolition policies, the trend appears to be toward greater regulation. Increased landfill tipping fees, additional recycling options, and increased environmental awareness are helping to push the general movement for material diversion and recycling. Moreover, although there are a number of passive (i.e., voluntary) programs throughout North America, the more recent programs seem to be focused on active programs supported by laws and regulations.

The Institute contacted several Canadian cities/regions regarding existing regulations or ordinances concerning the diversion of asphalt based roofing waste from construction and demolition projects, as well as average landfill tipping fees.

Results are summarized in the table below.

LOCATION	REGULATION	C&D LANDFILL FEES/COSTS
Halifax Regional Municipality, Nova Scotia	Yes, asphalt scrap must be sent to licensed C&D waste facilities	Mixed C&D $80-$90 per tonne;
Montreal, Quebec	No	C&D waste from borough residents: C$40 per load for first 12 loads in single year, thereafter C$100 per load
Vancouver, British Columbia	No	C$430.00 per each tandem axle trailer; C$520.00 per each tridem axle trailer
Calgary, Alberta	No	For 2006: C$46 per tonne; for 2007: C$50 per tonne; for 2008: C$54 per tonne
Toronto, Ontario	No, asphalt waste is deemed private waste and must be handled by private C&D waste facilities, but ultimately disposed of in landfill	$85/tonne
Winnipeg, Manitoba	No	C$22.50 per tonne

Source Various (available upon request).

5.2 Environmental Drivers for Asphalt Roofing Recycling

5.2.1 Landfill Capacity and Regulations

Nowhere in the country is landfill capacity more of an issue than in Ontario, and specifically in the GTA. The Ontario Waste Management Association estimates that the total waste requiring disposal in Ontario is 9.3 million tonnes annually. More than one-third of this waste finds its way to Michigan. Of the 3.6 million tonnes of Ontario waste going to Michigan, two-thirds are private sector waste, a portion of which is construction and demolition waste. The disposal capacity of Ontario landfills has been in decline for many years as capacity expansion has not kept pace with capacity demand. In 1989, there were 730 landfills in operation in Ontario; today there are only 81. And the bulk of construction and demolition waste capacity, as opposed to capacity for municipal solid waste, resides in 11 major private landfills. In essence, Ontario is dependent on a foreign jurisdiction to handle its solid waste. This situation has arisen out of a set of circumstances brought on by poor municipal planning, a provincial government continuously changing landfill environmental assessment policies and expansion rules, and fierce environmental lobbying.

Recently, Michigan municipal and state governments have been trying to limit the importation of solid waste from Ontario through enacting laws to ban foreign waste; however, these laws would not likely receive the necessary NAFTA exemptions required to make them stick. Meanwhile U.S. Homeland Security has weighed in, suggesting that the 350 trucks entering Michigan from Ontario every day may be hauling contraband a suggestion which may necessitate cumbersome and costly inspections at the border. The enormity of this potential problem is beginning to be realized.

In the fall of 2006, the Ontario government proposed new regulations to encourage municipalities and industry to divert waste from landfill and to support new waste technologies. The proposed regulations focus on three key areas: recycling, alternative fuels, and emerging waste technologies.

Below is a summary of the proposed new regulations that may have a bearing on asphalt roofing recycling.

Recycling barriers removed
The environment ministry proposed amendments to Ontario's General Waste Regulation, Regulation 347, that would facilitate recycling by municipalities and remove regulatory barriers that prohibit or limit recycling activities by others. Currently, the regulatory framework that governs the recycling of waste imposes strict controls on the handling of recyclable materials, and requires that a waste approval be obtained. This has been a longstanding criticism of recycling policy as it is seen to discourage recycling activities.

Beneficial use of wastes
The ministry reviewed the placement of waste materials on land for beneficial purposes, identifying the construction of walkways, roads and parking areas that involve deposition of materials on land as beneficial uses, rather than disposal. As a result, Regulation 347 could be amended to exempt these beneficial uses of waste from approval requirements. This exemption is intended to apply to waste asphalt shingles, waste asphalt and waste glass.

Encouraging alternative fuels
The ministry has proposed removing specific approval requirements for converting certain wastes into alternative fuels in order to encourage diversion of these wastes and

put them to beneficial use. All air emission approval requirements would still be applicable.

Further regulatory amendments are proposed to permit production of ethanol and biodiesel from biomass comprised of organic wastes and to permit their use as alternative fuels without the need for waste approvals (currently required). Production of energy from biomass is generally considered to have a neutral impact on greenhouse gas emissions.

Extended EPR

The ministry also intends to facilitate the development of more programs based on the principle of extended producer responsibility (EPR) to manage products when they become waste for reuse, recycling or proper disposal. Because these programs are a form of waste management, they currently require waste approvals. The ministry is proposing to exempt from the need for a waste approval any system based on extended producer responsibility that is designed and operated in accordance with the regulatory requirements. By providing a simpler regulatory mechanism for such systems, the ministry hopes to support the development of these programs, whether developed voluntarily or under the Waste Diversion Act.

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Asphalt Roofing Shingles in Asphalt Pavement
Date Published/Last Revised: Revised July 2006
3 page fact sheet: An overview of the use of ground asphalt roofing shingles in asphalt pavement, including potential markets and specifications.
CIWMB Publication Number: 431-97-033

Asphalt Roofing Shingles in Cold Patch
Date Published/Last Revised: Revised July 1999
3 page fact sheet: An overview of the use of ground asphalt roofing shingles in cold patch material for filling potholes and other uses. Includes a discussion of the technology and potential markets for recycled-shingle (R-S) cold patch.
CIWMB Publication Number: 431-98-013

Asphalt Roofing Shingles Recycling: Introduction
3 page fact sheet: An introduction to the recycling of asphalt roofing shingles (composition shingles). Includes information on quantities in the waste stream, composition, processing, and recycling issues.
CIWMB Publication Number: 431-97-031 July 2006

Appendix A

Annotated U.S. Asphalt Shingle Recycling

Project Summary

The following research project summary was provided by Mr. Dan Krivit, representing the Construction Materials Recycling Association, the developers of www.ShingleRecycling.org, a comprehensive clearinghouse of information on the subject.

A number of shingle recycling research and development projects are underway. This, along with the many other private development efforts, speaks to the need for continued communications and specification development at a national level.

The following list (with hyperlinks) itemizes some of the past, current and future shingle recycling projects (in reverse chronological order):

- SWMCB Tear-Off Shingles
- CMRA Tear-Off Shingles Project funded by U.S. EPA (2006)
- AASHTO Shingles Recycling Specification
- *Construction & Demolition Recycling magazine* article
- Minnesota Lab Research on Tear-Off Shingle Scrap
- Missouri Lab Research on Tear-Off Shingle Scrap
- RMRC Project #22
- RMRC Project #13 / #14: Specification Development
- SWMCB Manufacturers' Shingles
- Previous Mn/DOT projects
- CMRA Original Project (1999) and web site: ShingleRecycling.org

SWMCB Tear-Off Shingles

The SWMCB Tear-Off Shingle Scrap Recycling Project is intended to accelerate the development of a new infrastructure for recycling post-consumer asphalt shingles. SWMCB is working to demonstrate adequate government sector demand for end products such as hot-mix asphalt (HMA) derived from recycled tear-off shingle scrap.

This Project will also help expand the market for this emerging recycling opportunity by improving information and technology exchange between key players in the private and government sectors.

The Tear-Off Shingle Scrap Recycling Project is building upon the past SWMCB Manufacturers' Shingle Scrap Recycling Project plus ongoing research and development efforts by the Minnesota Department of Transportation (Mn/DOT), together with the Office of Environmental Assistance (OEA). Some of the original research was funded by these two state agencies more than 12 years ago.

For more information on the first SWMCB Manufacturers' Shingle Scrap Recycling Project, visit the Green Guardian web page: SWMCB Shingle Recycling
URL: http://www.greenguardian.com/business/shinglerecycling.asp

CMRA Tear Off Shingles Project funded by the U.S. EPA

The primary goal of this new EPA project is to develop and demonstrate recommended best practices that provide for superior quality assurance/ quality control (QA/QC) that can be utilized by profitable shingle recycling operators throughout the nation. The project has three principal objectives, according to the Construction Materials Recycling Association (CMRA):

- demonstrate successful and appropriate environmental/worker health protection procedures;
- document materials engineering benefits and methods of QA /QC to optimize their pavement performance effects; and,
- develop operational guidelines that maximize cost-efficiency while attaining minimum environmental, worker health and safety, and engineering standards.

The project will be produced by CMRA with key partner support from a wide variety of public and private agencies and companies. "This project will build directly on the substantial efforts of other research and development efforts such as the recent RMRC project #22 in order to help bring tear-off shingle recycling technology to full-scale implementation," says (William) Turley (Executive Director of the CMRA).

For more information about the project, the CMRA can be contacted at (630) 585-7530 or at info@cdrecycling.org.

For more information, see:
EPA news release: "Tear-off asphalt shingles recycling project receives $74,625 innovation grant" (5-27-05).

And see attached sidebar news article in: ***Construction & Demolition Recycling*** magazine July / August 2005 article under the feature CMRA News: "CMRA Granted Shingle Recycling Funding" (Volume 7, Number 3; Pages 14 – 15.)

Or click here: CMRA News or type into your browser's address bar:
http://www.cdrecycler.com/articles/article.asp?MagID=2&ID=4817&IssueID=224

AASHTO Shingles Recycling Specification

The American Association of State and Highway Transportation Officials (AASHTO) and its Subcommittee on Materials (SOM), are in the final stages of adopting a materials specification that itemizes specific quality assurance/quality control requirements for utilizing manufacturer and tear-off shingle scrap in HMA.

Detailed requirements include the following:

- the final RAS product must be sized and screened such that 100% passes the ½-inch sieve screen;
- maximum addition rate contractor option;
- gradation must meet the requirements of the mix design;
- deleterious material must not exceed a maximum of 0.50% by weight cumulative total (i.e., combination of all metal, glass, paper, rubber, wood, nails, plastic, soil, brick, tars and other contaminating substances); and
- asbestos level established by the state or U.S. EPA.

AASHTO is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 states, the District of Columbia and Puerto Rico. Its primary goal is to foster the development, operation and maintenance of an integrated national transportation system.

At its last meeting on August 10, 2005 in Santa Fe, NM, the AASHTO SOM, and its Technical Section 2c (Asphalt-Aggregate Mixtures), decided to recommend the proposed recycled asphalt shingle product specification for full committee balloting. It is expected that the full committee will approve the subcommittee recommendation and this will be published as a new AASHTO specification in 2006.

For more information on the results of this AASHTO SOM meeting, or a copy of the draft shingle recycling specification, contact:

Thomas E. Baker, P.E. (AASHTO Subcommittee, Tech Section Chair)
State Materials Engineer, Washington State Department of Transportation (WSDOT)
State Materials Laboratory, Environmental and Engineering Programs
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Olympia WA 98504-7365
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For more information on the original white paper produced for the Recycled Materials Resource Center (RMRC) that led up to this AASHTO shingles recycling specification, see the section below "RMRC Project #13 / #14: Specification Development".

Construction & Demolition Recycling Magazine Article

Many of the projects in this summary are mentioned in a recent article in *Construction & Demolition Recycling* Magazine (www.cdrecycler.com):
Construction & Demolition Recycling magazine July / August 2005 article: "Shingle – Minded Purpose" by Dan Krivit (Volume 7, Number 3; Pages 24 – 31.)
(click here: Shingle-Minded Purpose or type into your browser's address bar: http://www.cdrecycler.com/backissues/issue.asp?MagID=2&ID=224)

Minnesota Lab Research on Tear-Off Shingle Scrap

The Minnesota Office of Environmental Assistance (OEA), via a time sensitive grant through Dan Krivit and Associates (DKA), is funding this Minnesota Lab Study Project. This OEA project directly complements a parallel study sponsored by the Missouri Department of Transportation (MoDOT). (See MoDOT project description below).

The goal of this OEA Project is to complete the testing of samples adequate to allow Minnesota Department of Transportation (Mn/DOT) to recommend changes to the State hot-mix asphalt (HMA) pavement specifications that will allow the use of tear-off shingles in HMA as a normal business practice. The Minnesota OEA project has the following objectives:

1. Develop a study methodology to compare the relative impacts of tear-off vs. manufacturer RAS on HMA quality and performance. This methodology should use standard practices and methods whenever possible such that the tests can be replicated by other research in the future.
2. Measure total asphalt cement (AC) content (percent) and PG binder grade variability in tear-off shingle scrap compared to manufacturer shingle scrap and other control samples (i.e., Mn/DOT lab extraction and PG grading).
3. Conduct a controlled set of HMA laboratory analysis to provide empirical data of tear-off vs. manufacturer shingles and other control samples on HMA strength (i.e., U of M indirect tensile tests).
4. Conduct a controlled set of recycled asphalt shingles (RAS) analyses to develop standard practices and methods to measure relative amounts of deleterious materials in the ground/screened RAS product (before incorporating into HMA).
5. Analyze the data results, and if these indicate that tear-offs are safe and feasible, recommend a new Mn/DOT specification allowing tear-off shingles in HMA. The Mn/DOT Bituminous Engineer will consider developing such a new recycled shingle specification if the results indicate the tear-off-derived HMA is equivalent to, or better than, manufacturer-derived HMA.

For more information, see:
“Revised MN methods DK2 4-27-02”

Missouri Lab Research on Tear-Off Shingle Scrap

The Missouri project will provide the necessary similar and additional lab data to further analyze the hot-mix asphalt (HMA) supplemented with recycled asphalt shingles (RAS) produced from tear-off shingle scrap. The RAS-derived HMA test samples will be compared to control samples of HMA produced from 20% RAP, 0% RAS mixes. The University of Minnesota, Department of Civil Engineering, is already scheduled to perform similar lab analysis using its equipment to measure indirect tensile strength for the Minnesota Department of Transportation.

The project will result in verification or modification of requirements within the new draft Missouri Department of Transportation (MoDOT) specification on tear-off shingle recycling into HMA. This project will conduct additional empirical lab tests needed by MoDOT engineers in order to confirm requirements within their new draft specification allowing recycled tear-off shingles in HMA.

This Missouri project directly complements the Minnesota lab project (see project description above).

For more information about the MoDOT specification, see:

Construction & Demolition Recycling magazine May/June 2005 article: by Dan Krivit (Volume 7, Number 3; Pages 6 – 8.)

Click here:
Missouri Takes Lead in Shingle Recycling

Or type into your browser’s address bar:
http://www.cdrecycler.com/news/news.asp?ID=1959

RMRC Project #22

The Recycled Materials Resource Center (RMRC) funded a project produced principally by the Minnesota Department of Transportation (Mn/DOT). This RMRC Project, *Overcoming the Barriers to Asphalt Shingle Recycling* (RMRC Project 22), extends over 14 years of research and development in Minnesota and selected other states on recycling of shingle scrap. This RMRC Project focused on field-testing, market development, and technology transfer of tear-off shingle scrap recycling. The end-use road construction applications demonstrated included use of recycled asphalt shingles (RAS) as: (1) a dust control supplement; (2) an unbound aggregate supplement as base; and (3) a 5% blend into hot-mix asphalt (HMA). One of the first products was an “Environmental White Paper” documenting the results of a controlled personal air sampling of ambient dust generated from a shingle recycling operation. A major outreach strategy was the April 2003 Second Asphalt Shingles Recycling Forum held in Bloomington, MN.
In the past, the additional quality assurance / quality control (QA/QC) challenges of residential tear-off shingle scrap have been barriers to development of this type of asphalt

shingle scrap. In Minnesota, there is more demand for recycled manufacturer shingle scrap than available supply. Thus, there was a continued need to develop tear-off shingle recycling as addressed by this RMRC Project.

For more information, click here: *RMRC Project 22 Final Report*

Or type into your browser's address bar:
http://www.rmrc.unh.edu/Research/Rprojects/Project22/P22finalreport.asp

RMRC Project #13 / #14: Specification

There was substantial recycled shingles specification development work recently completed by the RMRC. This other related project sponsored by RMRC was the "Development and Preparation of Specifications for Using Recycled Materials in Transportation Applications" (RMRC Project #13 / #14). Conducted by Chesner Engineering, this related RMRC project resulted in the preparation of a draft shingle recycling specification submitted to the American Association of State Highway and Transportation Officials (AASHTO) for consideration and potential adoption. This RMRC Project #13 / #14 resulted in recommendations currently being acted upon by the AASHTO's Subcommittee on Materials (see AASHTO shingles recycling specification above for more information).

For more information, click here: RMRC Project #13 / #14 Shingles Recycling White Paper: **Reclaimed Asphalt Shingles in Asphalt Concrete**

Or type into your browser's address bar:
http://www.rmrc.unh.edu/Research/Rprojects/Project13/Specs/RASAC/p13RASAC.asp

SWMCB - Manufacturers' Shingles

In 2004, the Solid Waste Management Coordinating Board (SWMCB) completed a two-year study and developed recommendations on how to increase the recycling of manufacturer shingle scrap in the SWMCB region. County engineers were involved in discussions about the appropriate role of counties in encouraging hot-mixed asphalt (HMA) producers to use manufacturer shingle scrap in HMA used to pave county road construction projects. The project resulted in a web page on www.greenguardian.com to promote the recycling of manufacturer shingle scrap.

Since completing the project described above, the SWMCB has continued efforts to help expand the market for recyclable shingles. Ongoing SWMCB technical staff efforts include evaluation and promotion of proactive County procurement practices. Such practices recommended in the 2004 study include bid advisories and alternate bid language that indicates SWMCB Counties want to encourage highway paving bids that include hot-mix asphalt (HMA) with recycled shingle content. The SWMCB intends to continue with its market development efforts to promote use of tear-off (post-consumer) asphalt shingles and is a partnering organization in the new EPA funded project being produced by CMRA (see project description above).

For more information, click here:
SWMCB's Green Guardian – Shingle Recycling web page

Or type into your browser's address bar:
http://www.greenguardian.com/business/shinglerecycling.asp

Previous Mn/DOT projects

There is a substantial amount of previous research and feasibility work (informally referred to as "Phase One") conducted for Mn/DOT in the early 1990's. Within "Phase One", a series of three studies was sponsored and published by Mn/DOT:

- Turgeon, Curtis M., "Waste Tire & Shingle Scrap Bituminous Paving Test Sections On The Munger Recreational Trail Gateway Segment." Office of Materials and Research, Minnesota Department of Transportation, February, 1991.
- Newcomb, David E., Mary Stroup-Gardiner, Brian M. Weikle, and Andrew Drescher, "Properties of Dense-graded and Stone-mastic Asphalt Mixtures Containing Roofing Shingles." ASTM Special Publication 1193, ASTM, 1993.
- Newcomb, David, et al., "Influence of Roofing Shingles on Asphalt Concrete Mixture Properties." Report MN/RC-93/09, University of Minnesota, Minnesota, 1993.

Summary & Abstract
(http://www.moea.state.mn.us/lc/purchasing/newcomb-summary.pdf)
Full report
(http://www.mrr.dot.state.mn.us/research/MnROAD_Project/MnRoadOnlineReports/93-09.pdf)

- Janisch, D. W. and C.M. Turgeon, "Minnesota's experience using shingle scrap in bituminous pavements. Final report, 1991-1996." Minnesota Department of Transportation, Maplewood, MN. Report No. PB-97-132278/XAB MN/PR--96/34, October 1996.

These earlier research and development projects led to the first version of the Mn/DOT materials specification in 1996 to allow up to 5% manufacturer scrap shingles in certain asphalt hot-mixes.

The "Phase Two" Mn/DOT Project (approximately 1997 through 2002) was focused on outreach to expand implementation of manufacturer shingle scrap recycling. The top Phase Two priority was to increase utilization into HMA as per the current Mn/DOT specification.

A result of the Mn/DOT *"Phase Two" Project* was an information "tool kit". Mn/DOT published this as, A Guide to the Use of Roofing Shingles in Road Construction: It's All Part of the Mix and included the following fact sheets:

Project Overview

Minnesota Research

Case Studies

Economics

Vendors of Shingle-grinding Equipment (updated by the SWMCB, February 2004)

For more information

The Minnesota Office of Environmental Assistance (OEA) helped further disseminate this shingles recycling Guide via the OEA Environmentally Preferable Purchasing web page, www.moea.state.mn.us/lc/purchasing/shingles.cfm ,
with the subsequent links to view the individual fact sheets as listed (and hyperlinked) above.

This Guide packet was originally mailed out under signature of Patrick C. Hughes, Mn/DOT Office of Materials & Road Research, in September 2002 to local engineers, hot-mix asphalt producers, shingle manufacturers, solid waste / recycling officials, and other interested parties. It was subsequently used at related industry conferences, workshops and other forums.

CMRA Original Project: Shingle Recycling.org

The Construction Materials Recycling Association (CMRA) is the lead sponsor of the Asphalt Shingles Research Assessment Project (ASRAP), an ongoing, long-term development project to improve the market for asphalt shingles. Other co-sponsors include the University of Florida (Gainesville, FL), the National Roofing Contractors Association (NRCA), and U.S. EPA. (Region 5, Chicago, IL). The ASRAP project was initiated at the *First Asphalt Shingles Recycling Forum* held in Chicago in November 1999. The project began a survey of state agencies and private recyclers in 2001 and culminated in the publication of the web page www.ShingleRecycling.org, a comprehensive clearinghouse of information on the subject. The 2001 survey identified individual state regulations, asbestos sampling data, and other research and development projects being conducted around the country.