Environmental Issues Associated With Asphalt Shingle Recycling

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EXECUTIVE SUMMARY

The practice of recycling waste asphalt shingles has gained momentum in recent years. Cited benefits of recycling asphalt shingles include the marketability of materials that can use processed asphalt shingles as a component and the conservation of landfill airspace. However, regulatory concerns over potential environmental impacts, particularly with regard to asbestos, have to some extent limited the widespread recycling of discarded post consumer asphalt shingles. A critical evaluation of data and information related to asphalt shingle recycling was conducted, including a review of available asphalt shingle manufacturer data, federal and state regulations, trade association literature, laboratory data, and data from asphalt shingle recycling facilities. This document reports the results of an effort to summarize relevant information pertaining to possible environmental issues associated with the recycling of discarded (post-manufacture and post-consumer or tear-off) asphalt shingles.

An extensive review found that the primary environmental concern linked to recycling asphalt shingles is the possible presence of asbestos. Asphalt shingles consist of a fiber mat that is impregnated with asphalt, along with other mineral additives. Asbestos is a naturally occurring mineral which, because of its fibrous nature and attributes such as strength and thermal resistivity, made it a popular component of many construction products in much of the last century. A review of manufacturer sales literature found that several different types of asphalt roofing products contained asbestos (e.g., mastic, rolled roofing); relative to these other types of asphalt products, asphalt shingles were rarely encountered in the trade literature as containing asbestos. Detailed manufacturing data regarding the amount of asbestos used in asphalt shingles are not available, though anecdotal reports do suggest that asbestos was used in some asphalt shingles until the early 1980s. The expected lifetime of asphalt shingles and the somewhat limited use of asbestos in asphalt shingles suggest that the probability of encountering an asphalt shingle containing asbestos is small. Several shingle recyclers have tested for the presence of asbestos in their shingle supply. Data were compiled from many of these recyclers. Asbestos was detected in just over 1% of the samples (out of over 27,000 samples). In many cases, the asbestos occurrence was attributed to other materials present in the sample.

Since asphalt shingles are a petroleum-derived product, some questions have been raised concerning the presence of PAHs, specifically whether ground up recycled asphalt shingles pose either a direct exposure or a leaching risk, or whether the use of recycled asphalt shingles in hot mix asphalt (HMA) production has an impact on PAH emissions. Asphalt does contain small amounts of PAHs, and if shingles themselves are compared to risk-based thresholds for clean soil, a few PAH concentrations may be greater. For applications where ground shingles have been land applied without encapsulation in pavement, this concern has been addressed by blending the shingles with other materials and requiring permitting prior to use of the mixture. The question of PAH emissions from HMA plants using shingles has been raised, but no data exists to suggest that such practices would result in any different PAH emissions relative to HMA using virgin asphalt sources.

The review of existing and available information suggests that recycling of asphalt shingles, especially into HMA, is technically feasible and is likely to offer economic and environmental benefits. The information gathered also suggests that the occurrence of asbestos in tear-off shingles from residential reroofing projects will be minimal, but that the recycling facility operator should expect to encounter asbestos-containing material on occasion and thus should

be adequately prepared to monitor and manage such debris. Environmental risks associated with PAH migration appears to be small and comparable to that presented by any asphalt-containing material. Regulatory agencies are faced with the challenge of providing regulations, policies and permit conditions that provide for protection of human health and the environment, and that are appropriate for the risk presented and not unnecessarily conservative (and thus inhibitory to recycling efforts). Suggestions are provided on provisions to include in facility permits that work toward meeting these objectives.

1. INTRODUCTION

Asphalt roofing shingles are one of the major components of the debris generated from construction, demolition, and renovation projects (EPA 1998). Asphalt shingles are the most common type of roofing material used in both new homes and roof replacements, accounting for more than 60% of the residential roofing market in the United States (FVD 2006; NAHB 1998). Approximately 11 million tons of asphalt shingle waste is generated each year in the United States (US) (CIWMB 2007; CMRA 2007; Sengoz and Topal 2005; Zickell 2003). The majority of waste shingles are from building activities, primarily renovation and demolition; however, waste is also produced by shingle manufacturers (EPA 1998; NAHB 1998). Currently, the most common disposal method for asphalt shingles in the US is landfilling (Mallick and Teto 2000; Zickell 2003). Waste asphalt shingles do, however, offer a strong potential for recovery and recycling, and this has led to significant growth in the asphalt shingle recycling industry in recent years.

Asphalt shingle recycling has been identified as possessing a market potential greater than most other components of construction and demolition (C&D) debris (Cochran 2000). The potential markets for waste asphalt shingle recycling include use in hot mix asphalt (HMA) and cold asphalt patching, use in roadways as dust control for rural roads (e.g., as temporary roads and driveways), and as a fuel in cement kilns (CMRA 2007; EPA 1998; Foo *et al.* 1999; Mallick and Teto 2000; Marks and Gerald 1997; Sengoz and Topal 2005). Asphalt shingle recycling will not only reduce the requirement for the virgin materials that the shingles are replacing (e.g., asphalt and aggregate in the HMA market), but will also reduce the consumption of landfill airspace. In addition, shingle recycling may reduce the emission of potentially hazardous components associated with the mining, production and transport of virgin materials used in the manufacture of asphalt and aggregates (Sengoz and Topal 2005).

The results from multiple research projects indicate that recycling asphalt shingles is technically feasible (Decker 2002; Grodinsky *et al.* 2002; NAHB 1998; Sengoz and Topal 2005); however, asphalt shingle recycling is rarely practiced in some states. Major issues that have been raised as impediments to the recycling of waste asphalt shingles, especially post-consumer shingles ("tear-offs"), are environmental and regulatory concerns, particularly with regard to asbestos (ARMA 1998; CIWMB 2001; CMRA 2007; Lee *et al.* 2004; Marks and Gerald 1997; NAHB 1998; Zickell 2003). Although asbestos has not been used in the manufacture of asphalt shingles for over two decades, asbestos is occasionally encountered in older shingles or in other roofing products.

Asphalt shingle recycling has also been found to demonstrate environmental benefits. Cochran (2006) conducted a life cycle analysis that compared recycling of asphalt shingles (separated at the job site or separated at a materials recovery facility (MRF)) with disposal (in an unlined or a lined landfill). In this analysis, shingle recycling reduced the environmental and energy burden associated with the manufacture of asphalt using crude oil, but added some burden as a result of the requirement for processing the shingles prior to reuse. The results of this analysis found that the net energy requirement associated with recycling shingles into HMA was less than the requirement associated with disposing these shingles in a landfill and using virgin materials for HMA production.

The environmental and economic benefits associated with asphalt shingle recycling must be balanced with environmental and regulatory concerns. Recycling operations should comply with necessary operational and monitoring practices to provide adequate protection of human

health and the environment. Determination of appropriate operational and monitoring constraints, however, has been limited by a lack of sound information on the true risks. The purpose of this white paper is to provide a summary of available information on possible environmental issues associated with asphalt shingle recycling and to give some guidance on the practices that can be implemented to provide environmental protection appropriate to the expected risks. This document does not provide detailed technical information on the shingle recycling process and items such as supply sourcing, collection, processing, end use, testing, and economics. The reader should consult other documents for this information (e.g., Krivit and Associates 2007).

The white paper is organized into eight sections. Section 2 presents a background discussion of asphalt shingle composition, production method, and waste asphalt shingle generation. Section 3 presents a discussion of asphalt shingle recycling, including common end uses and associated environmental concerns with these end uses. Section 4 focuses on issues related to asbestos, including identifying historical information regarding the inclusion of asbestos in asphalt shingles, asbestos-related regulations, and results of case studies in the US that have measured the asbestos content of pre- and post-processed asphalt shingles. Section 5 discusses issues related to PAHs, with specific regard to potential PAH emissions and leaching of PAHs during the production and use of recycled waste asphalt shingles. A summary of the white paper is presented in Section 6, recommendations are presented in Section 7, and references are provided in Section 8. The white paper is intended as a resource to parties that may have an interest in the process of recycling asphalt shingles, including industry, regulators, consultants and engineers.

2. BACKGROUND

2.1 Asphalt Shingle Production

2.1.1 History of Asphalt Shingles

Asphalt has been used as a building construction material for thousands of years (Blachford and Gale 2002). The forerunner of the asphalt shingle, asphalt-prepared roofing, was first manufactured in the United States in 1893 (Blachford and Gale 2002; Cullen 1992). The first asphalt shingles appeared in 1901 with slate granules as surface protection (Cullen 1992). During the ensuing years, asphalt shingles became more and more popular in the roofing market, with cited benefits (relative to other roofing materials such as wood and aluminum) including ease of installation, light weight, low cost, and low maintenance requirements (Blachford and Gale 2002). By the late 1930s, 32 manufacturers produced over 11 million squares of asphalt shingles, enough to cover about 45 percent of US residential homes (Cullen 1992). Currently, approximately 12.5 billion square feet of asphalt shingles are manufactured annually, which is enough to cover about five million homes (ARMA 2007). In the US, approximately 80% of homes are covered with asphalt shingles.

2.1.2 Asphalt Shingle Composition and Manufacturing Procedure

A typical asphalt shingle consists of different materials, including a granular/aggregate surface, asphalt, an asphalt-impregnated mat (commonly composed of a fiberglass or organic felt), and fine mineral base, as shown in Figure 1. The base material provides the matrix to support the other components, while the asphalt provides weather resistance, increases the stability of the shingle under extreme temperatures, and waterproofing. The granular/aggregate surface on top, usually consisting of granular ceramic, protects the asphalt from damage caused by the sun and adds a desired color to the product. The surface granules may also contain a chemical such as copper to inhibit algae growth during the shingle's service life (3M 2007). Organic felt is made of cellulose fibers, while the fiberglass mat is generally made by chopping fine glass filaments and mixing them with water to form a pulp, which is then formed into a sheet (Blachford and Gale 2002). The bottom surface of the shingles is coated with sand, talc, or fine particles of mica (Blachford and Gale 2002; Grodinsky et al. 2002; USGS 2004). Table 1 presents the typical composition of asphalt shingles. The American Society for Testing and Materials (ASTM) has developed specifications for roofing shingles: ASTM D 225-86 (Asphalt Shingles (Organic Felt) Surfaced with Mineral Granules) and ASTM D3462-87 (Asphalt Shingles Made from Glass Felt and Surfaced with Mineral Granules) (Grodinsky et al. 2002).

Asphalt is a dark brown to black cement-like semisolid, solid or viscous liquid produced during petroleum refining (Wess *et al.* 2004). Before being used in the manufacture of shingles, asphalt must be converted to oxidized asphalt in a process called "blowing", which bubbles oxygen into the liquid asphalt and increases its viscosity (Blachford and Gale 2002; NIOSH 2001; Wess et al. 2004). The process is monitored and stopped when the desired properties are produced (NIOSH 2001).

The manufacture of asphalt shingles consists of six major operations (NIOSH 2001):

The process begins with a layer of organic (cellulose or wood fiber) or fiberglass fiber mat. The base material passes through a saturator tank filled with hot asphalt. Once coated with the appropriate thickness of asphalt, one side of the shingle is then surfaced with granules for protection against physical damage and sun damage. The granules exposed in the roofing application are comprised of crushed rock coated with ceramic metal oxides. A light coating of fine sand is applied to the back surface of the shingle to prevent the individual shingles from adhering to each other during packaging and transport. The final steps in the production of asphalt shingle are the finish, cutting, and packaging (NIOSH 2001).

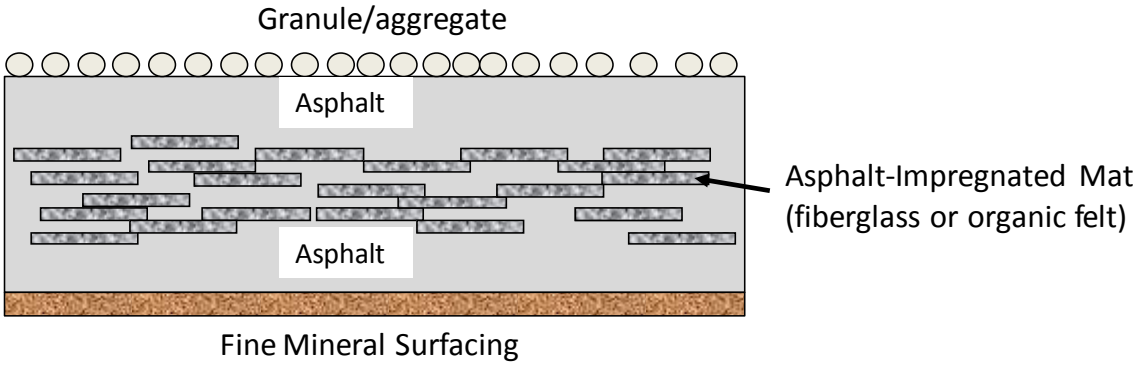

Figure 1. Schematic of Asphalt Shingle Composition

Table 1. Typical Composition of Asphalt Shingles

Component	Organic Shingles (%)	Fiberglass Shingles (%)
Asphalt cement	30-36	19-22
Felt	2-15	2-15
Mineral granules/aggregate	20-38	20-38
Mineral filler/stabilizer	8-40	8-40

Note: from (CIWMB 2007; NAHB 1998)

2.2 Management of Asphalt Shingle Waste

2.2.1 Sources and Generation

Generally, there are two main sources of asphalt shingle waste: post-manufacture and post-consumer ("tear-off"). Post-manufacture asphalt shingle waste is a scrap fraction that remains after the manufacturing process of asphalt shingles, whereas post-consumer asphalt shingle waste results from building activities such as construction, demolition, and renovation. The majority of asphalt shingle waste generated in the US is post-consumer (NAHB 1998). Post-manufacture and post-consumer asphalt shingle waste may be mixed with other materials that must be separated prior to processing, which can include materials such as wood, plastic wrap, and other deleterious materials.

2.2.1.1 Post-manufacture

Annually, approximately 11 million tons of asphalt shingle waste is generated in the United States, of which approximately 5 to 10 % (550,000 to 1,100,000 tons) is generated post-

manufacture or scrap (Sengoz and Topal 2005; VANR 1999; Zickell 2003). From each specific type of shingle manufactured, the post-manufacture scrap is generally uniform and homogeneous (NAHB 1998).

2.2.1.2 Post-consumer

The majority of asphalt shingle waste comes from post-consumer waste. In general, the lifetime of an asphalt shingle roof ranges between approximately 12 to 25 years; ultimately, the service life depends on the shingle manufacturing technology employed (Cullen 1992). It has been estimated that approximately 7 to 9 million tons of discarded post-consumer shingles are generated annually in the US (VANR 1999). Most of the discarded post-consumer asphalt shingle waste is generated at residential sites during construction, demolition, and renovation, and the remaining asphalt shingle waste stream is generated by non-residential demolition sites. Unlike post-manufacture shingles, the discarded post-consumer asphalt shingles may be composed of shingles of varying asphalt and aggregate composition, may be from multiple manufacturers, and may have undergone weathering and aging from exposure to ultraviolet sunlight (Foo *et al.* 1999; NAHB 1998). Furthermore, discarded post-consumer asphalt shingles may contain several layers of shingles, as a common practice in re-roofing is to install new roof shingles on top of older ones.

2.2.2 Collection/Processing

Post-manufacture shingle scrap is normally unused, clean, and in some cases bundled. It consists of a combination of remnants and scraps from the manufacturing process as well as damaged or off-specification shingles. Since it does not contain any other materials as potential contaminants (e.g., nails), it is often the most sought after shingle scrap for recycling. It is noted that packaging materials such as bags and strapping, if present, must be removed prior to recycling post-manufacture asphalt shingles. These shingles can be collected easily by a recycler or delivered by the manufacturer directly to a recycling operation. Post-consumer shingle waste, however, is not usually bundled and may be mixed with other materials found in the C&D waste stream.

2.2.3 Landfilling

Currently, the majority of asphalt shingle waste is managed by landfilling (Zickell 2003). Waste asphalt shingles are typically accepted at C&D debris landfills. Some landfills separate incoming waste shingle loads (and charge a lower tipping fee) and use them as road base material or pads for trucks. Landfilling of asphalt shingles diminishes available landfill airspace; since the materials that comprise an asphalt shingle are similar to those materials used in HMA and other road applications, discarded asphalt shingles have been identified as a material that may be readily diverted from landfill disposal and beneficially reused.

2.2.4 Recycling

Both post-manufacture and post-consumer waste shingles require processing before they can be recycled. The first step of the recycling process is to remove all non-shingle waste from the waste stream. For most recycling applications, the waste shingles are then size-reduced. Various complex grinding and screening methods have been utilized to process shingles for recycling, including shredders, hammer mills, and different screens. Magnets may be utilized to remove nails after shredding, and blowers or vacuums may be used to remove paper and other lightweight contaminants. Mixed C&D recycling facilities typically have a picking line where the asphalt shingles are separated from other contaminants such as metal flashing, roofing paper,

wood fragments, and other unacceptable material (Chesner Engineering 2003). Water is sometimes added during shredding to keep the shingles cool and to control dust. After grinding, the shingles can be fed to a screen to achieve the desired product size. Shingles that are not small enough to fall through the screen may be used for a process with larger size specifications or they may be fed back into the grinder for further size reduction (Grodinsky et al. 2002; Marks and Gerald 1997; VANR 1999; Zickell 2003). The potential markets include use in HMA, in cold (asphalt) patching or roadways, as dust control for rural roads, as temporary roads and driveways, as a road/driveway aggregate base, in new shingle manufacturing, as a fuel supplement in cement kilns, and as mulch (CIWMB 2007; CMRA 2007; Grodinsky et al. 2002; RMG 2001). Specific recycling practices are discussed in greater detail in the next section.

3. ASPHALT SHINGLE RECYCLING

3.1 Overview

In general, asphalt shingles are recycled either at dedicated recycling or processing facilities (those that only accept asphalt shingles) or at mixed C&D debris recycling facilities (which accept different components of the C&D waste stream). The recycling process for post-consumer asphalt shingle waste typically begins at the construction site, where shingle remnants from the installation process and unused shingles are typically placed in a waste container with other debris components. However, construction contractors may also provide separate bins for different waste components as part of an effort to recycle construction debris; this practice helps minimize contamination. When good job site separation practices are in place, the result is a higher quality post-consumer material. Most post-consumer shingle scrap is produced from reroofing jobs when an old set of shingles is removed and replaced with new shingles. Shingle debris generated from renovation and demolition activities has the potential to contain other materials such as wood, nails, paper, packaging, and other debris (NAHB 1998). Post-consumer roofing materials (which includes asphalt shingles, but may also contain other roofing materials such as tarpaper) may also be separated out at mixed C&D debris recycling facilities.

One goal of asphalt shingle separation at C&D recycling facilities is to ensure compliance with asbestos regulations (typically accomplished by following an approved sampling protocol) to reduce the likelihood of asphalt shingles containing asbestos from being processed. The exact protocol for separation and processing of asphalt shingles at these facilities may vary depending on the quantity and nature of other materials received and processed, but one practice that is employed at C&D recycling facilities in states that require asbestos testing on asphalt shingles is to have a staging area where incoming roofing waste loads are held while asbestos analytical results are obtained. Once analytical results indicate that the shingles do not contain asbestos, they are then moved from the staging area to the processing area, where the asphalt shingles are separated. More details regarding techniques for separation and processing of asphalt shingles can be found in Krivit and Associates (2007).

3.2 HMA

Currently, HMA is the largest recycling market for waste asphalt shingles. Asphalt shingles are utilized two ways in HMA production: as a binder and as an aggregate (Foo et al. 1999; FVD 2006; Sengoz and Topal 2005). Because of its adhesive characteristics, flexibility, and ability to form strong cohesive mixtures with mineral aggregates, asphalt is widely used in the HMA industry for producing paving materials. Asphalt shingles contain approximately 19 to 36% asphalt by weight (CIWMB 2007; NAHB 1998). In addition, the ceramics in the shingles (approximately 20-38% by weight) are a source of aggregate used in HMA.

A number of laboratory and field-scale research studies have been conducted to evaluate the use of asphalt shingles in HMA and stone matrix asphalt (SMA). Based on the results reported in the literature, the following benefits may be derived from using waste asphalt in HMA (Ali et al. 1995; Brock and Shaw 1989; Button et al. 1995; Foo et al. 1999; Grzybowski 1993; NAHB 1998; Rajib *et al.* 2000; Sengoz and Topal 2005):

- Reduced demand on virgin asphalt cement and aggregate;
- Improved resistance to pavement cracking and rutting due to the reinforcement provided by fibers contained in shingles; and

- Reduced production cost of HMA.

3.3 Other Uses

3.3.1 Cold Patch

The use of recycled asphalt shingles as cold patch is a practice that has been employed extensively in some regions of the US (Grodinsky et al. 2002). Cold patch generally consists of asphalt, aggregate, and a solvent. Ground asphalt shingles are typically mixed with aggregate and an emulsion to produce a patching mix. Potholes can be filled and roads are patched with this mixture. The use of recycled shingle-containing cold patch may have the following benefits (CIWMB 2007):

- Preservation of landfill space by diverting asphalt shingle waste,
- Improved pavement performance because of the fiberglass and/or cellulose fibers in the shingles,
- Potential economic savings due to longer life and decreased maintenance costs relative to non-shingle containing cold patch, and
- Ease of use due to lighter weight, lack of equipment needed, and time flexibility.

3.3.2 Aggregate in Road Construction

Recycled asphalt shingles have been used as an aggregate in road construction or maintenance. The shingles are first ground and screened to produce the appropriate particle size, then mixed with gravel. These aggregates are typically used to cover rural, unpaved roads. The mixture leads to several improvements in these rural roads, including minimizing dust, reducing vehicle noise, and requiring less road maintenance (CIWMB 2007; Marks and Gerald 1997). The North Carolina Department of Transportation has conducted several pilot projects using recycled shingles in road pavement in the Raleigh area (Nelms 1996). A study conducted by the Iowa Department of Transportation showed little or no dust for two years on a rural road with the addition of recycled asphalt shingles to the gravel. The roads have a longer life and require less maintenance (Marks and Gerald 1997).

3.3.3 New Shingle Manufacturing

In addition to road-related applications, attempts have been made to use recycled asphalt shingles to make new roofing shingles. Members of the Asphalt Roofing Manufacturers Association (ARMA) conducted factory-scale tests to evaluate the performance of equipment used for recycling asphalt shingles into new shingles, in addition to the technical and economical feasibility of recycling fresh factory waste into coating asphalt used to produce new fiberglass shingles (Snyder 2001). However, it was noted that some manufacturers had difficulty in meeting product specifications when recycled shingles were used in the production of new asphalt shingles (Snyder 2001).

3.3.4 Energy Recovery

Since asphalt has an energy value of approximately 20,000 BTU per pound (Mallick and Teto 2000), asphalt shingles may also be recycled to recover the energy in asphalt (i.e., used as a fuel supplement). The recovery of the BTU value of waste shingles is an established market in Europe, while the concept has only recently been applied in the US (CMRA 2007). Based on the percent composition of asphalt in shingles presented in Table 1, an organic felt-based asphalt

shingle may have a BTU value ranging from 6,000 to 7,200 BTU/lb and a fiberglass mat asphalt shingle may have a BTU value ranging from 3,800 to 4,400 BTU/lb. Others have reported energy content measurements of recycled asphalt shingles as high as 8,500 BTU/lb (Edwards 2007). A reported concern with using asphalt shingles as a fuel supplement has been the release of asbestos at combustion temperatures below 1,800 °F (GDNR no date); however, this would only be a concern if asbestos was present in the asphalt shingle. One example application where recycled asphalt shingles have been used in energy recovery is in cement kilns. The organic portion of the shingle is used as a fuel supplement while the inorganic portion of the shingle remains in the kiln and becomes part of the kiln's clinker, which is a solid material that has sintered into nodules or lumps (Krivit and Associates 2007; Ash Grove 2007). More details on the use of recycled asphalt shingles as part of the cement production process can be found in Krivit and Associates (2007).

3.4 Overview of Environmental and Health Concerns With Asphalt Shingle Recycling

Although the market and technologies for asphalt shingle recycling are available, nationwide acceptance and commercialization of recycling shingles, especially post-consumer shingles, is much less developed. As described in the opening of this document, one of the main impediments to more widespread post-consumer asphalt shingle recycling involves regulatory concerns of environmental issues. The primary concern involves potential harmful environmental emissions of asbestos minerals that could possibly be contained in the shingles during asphalt shingle processing. Historically, asbestos minerals have been used in a number of roofing products, and thus may be present to some degree in roofing debris. A secondary concern is the release of PAH compounds, a group of organic chemicals that naturally occur in petroleum, many of which are known to have detrimental human health impacts at elevated levels of exposure.

Figure 2 illustrates potential exposure pathways of asbestos and PAH compounds during the asphalt shingle recycling process. The risk pathways of greatest concern to the recycler are those associated with the processing of the waste (potential impact to on-site workers and to nearby residents) and those related to the recycling of the product (potential impact on employees at the recycling operation and on populations exposed to the recycled products). Asbestos is primarily an air emission concern, and thus the emission of asbestos fibers during grinding would possible pose a serious human health impact. The possible risk pathways for PAH compounds are less well understood, but issues have been raised with respect to PAH migration to water, direct exposure of humans to PAH compounds in processed shingles, and release during use at HMA facilities. These exposure pathways will be discussed in more detail in Section 4 and Section 5.

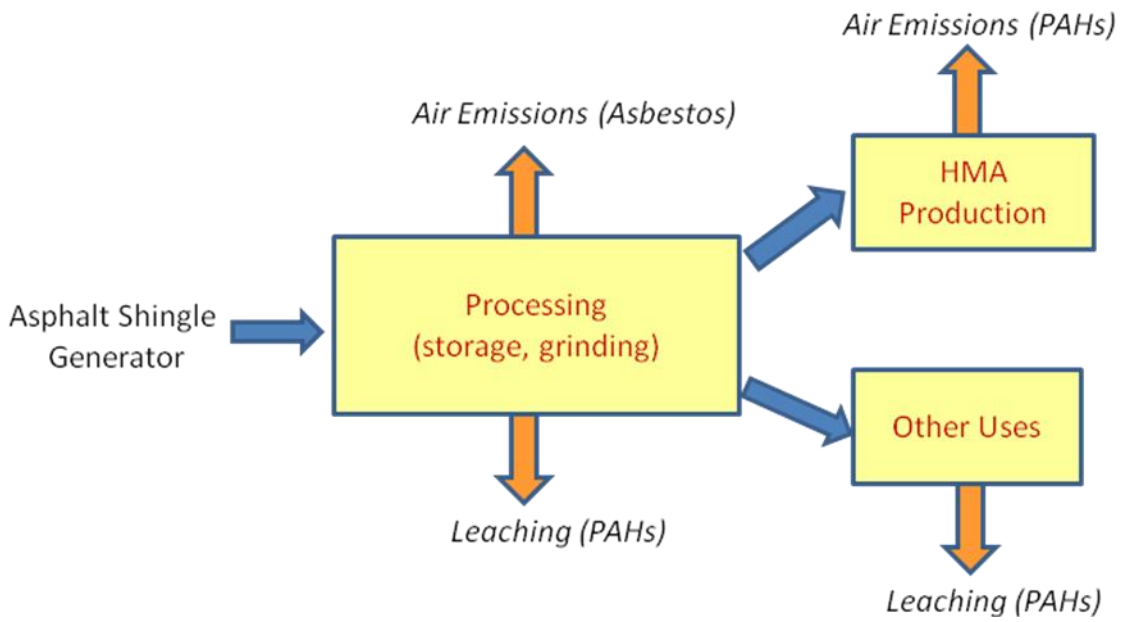

Figure 2. Potential Exposure Pathways of Asbestos and PAHs during Asphalt Shingle Recycling

4. ASBESTOS ISSUES

Asbestos is the name given to a number of naturally-occurring fibrous silicate minerals, including: chrysotile, crocidolite, amosite, anthophyllite, tremolite, and actinolite (ATSDR 1995a; OSHA 2002b). The most commonly-used asbestos fiber in roofing materials is chrysotile; as a result, this is the asbestos fiber that is most commonly detected in recycled asphalt shingle samples. Another type of shingle was historically produced with asbestos, referred to as asbestos shingles (also known as transite), which were typically a rigid board type material made up of asbestos mineral fibers and Portland cement mixtures. This section presents a discussion of the historical use of asbestos in roofing products, the associated asbestos regulations, as well as case studies from asphalt shingles recyclers throughout the US that measured the asbestos content of discarded asphalt shingles.

4.1 Asbestos in Asphalt Roofing Products

Because of its stable mechanical and thermal properties, numerous industries utilized asbestos in construction products such as asphalt and vinyl floor tiles, asphalt-containing roofing material, cement wallboard, and heating and electrical ducts. Data published in the Federal Register in 1990 listed several manufacturers that utilized asbestos in their products, some of which included manufacturers of asphalt roofing products (EPA 1990d). Table 2 presents a summary of information published in the Federal Register, in addition to manufacturer data collected from other sources (EPA 1990d; Johns-Manville no date; Amianthus no date). Asbestos was historically used in asphalt shingles to act as a reinforcement (i.e., mat) for the shingle and also acted as a fireproofing/insulating material.

Table 2. Summary of Asbestos-containing Asphalt Roofing Products

Manufacturer	Years Manufactured	Product
Barber Asphalt Corporation	NA	Asphalt-asbestos roof felt
Carey Manufacturing Company	NA	Asphalt-asbestos shingles, asbestos finish felt, mastic
The Celotex Corporation	1906 through 1984	Asphalt roof coating and other miscellaneous materials
Fibreboard Corporation	1920 to 1968	Roof paint, roll roofing with asbestos-containing base sheets, caulking compounds, plastic cements, taping and finishing compounds
General Aniline and Film Corporation	NA	Roofing asphalt
Johns-Manville Corporation	1891 through 1983	Asphalt-asbestos shingles, rag-felt shingles, fibrous roof coating, shingle tab cement, roof putty
Kaylite Company	NA	Asbestos surface coating for shingles
National Gypsum Company	1941 through 1981	Roofing and shingles
Monroe Company	NA	Asbestos surface coatings for shingles

Manufacturer	Years Manufactured	Product
Rhone-Poulenc Ag Company	Early 1930s through 1976	Adhesives, coatings, sealants, and mastics
United States Gypsum Company	1930 through 1977	Paper and felt

Note:
NA = Information not available.

The following is a description of some of the asbestos-containing asphalt roofing products presented in Table 2:

- Asbestos roof felt: Also referred to as asbestos roof mat, it is a component that is impregnated in asphalt that was used as an insulating and waterproofing material between roof boards and shingles (Johns-Manville no date). These roof mats were widely used in "built-up" roofs in the US (EPA 1990c).
- Asbestos roof putty: This was a plastic cement used to stop leaks due to holes in shingles, roofs, or slates (Johns-Manville no date).
- Asbestos surface coating: This was a siding and roof coating designed for the application to exterior (and interior) surfaces of asbestos shingles, applied by spray or brush (Amianthus no date).
- Mastic: A paste-like material used as an adhesive or seal.

In the 1970s, asbestos was banned from many uses when it became widely understood that workers who had been chronically exposed to the material developed cancer, asbestosis, and related diseases (NAHB 1998). However, asbestos was not banned from all products, and available information indicates that some asphalt roofing products containing asbestos were manufactured after the 1970s. According to the US Geological Survey (USGS), there has been no asbestos mining in the US since 2002, but asbestos is still imported and utilized in roofing products, totaling about 55% of the approximately 3,500 tons consumed in the US in 2007 (USGS 2007). The roofing products that still utilize asbestos include roof coatings, cements, and mastics (USGS 2007; Virta 2007). According to the USGS and the Asbestos Information Association/North America (AIA/NA, an asbestos industry trade group), asbestos is not used in the production of asphalt shingles today, and was phased out as a material used in the production of asphalt shingles in the early 1980s (USGS 2007; AIA/NA 2007).

There are limited data available regarding the asbestos content used in roofing products, including asphalt shingles. Manufacturer data regarding asbestos content in shingles is sparse, possibly because (a) potential liability concerns, (b) the companies that manufactured asbestos-containing asphalt shingles no longer exist, or (c) the data are simply not available. Johns-Manville Corporation, who began manufacturing asbestos-containing roofing products in the late 1800s, manufactured asbestos-asphalt roofing shingles (further described as asphalt-impregnated asbestos-fiberglass reinforced shingles) from 1907 to 1979 that contained between 35 and 50% asbestos (EPA 1990d). It is noted that this data may not necessarily be representative of the amount of asbestos used in the manufacture of asphalt shingles by others,

but the data do indicate that the amount of asbestos used by some manufacturers was significant.

Typically, roofs are replaced every 12 to 25 years; however, it is not uncommon to install new roofing shingles on top of old ones, and as a result, roofing shingle waste may sometimes contain two or three layers of old shingles (RMG 2001). Despite this, one still may expect the occurrence of asbestos in discarded post-consumer asphalt shingles to decrease over time given that asbestos use in roofing products was mostly eliminated in the 1970s.

4.2 Environmental and Health Concerns With Asbestos

Asbestos is the generic name for a variety of naturally-occurring minerals and is composed of silicon, oxygen, hydrogen, and various metal cations (ATSDR 1995a; EPA 1990a). The Department of Health and Human Services has identified asbestos as a known human carcinogen (ATSDR 1995a), and chronic exposure to asbestos may cause a number of deleterious health conditions, including lung cancer, asbestosis, and mesothelioma (EPA 1990a; Faust 1995; Krumm 2002; Lee and Cooper 2004). Epidemiological studies of workers exposed to asbestos indicate that inhalation of asbestos is the principal route of exposure (ATSDR 1995a). The risk for asbestos-related disease depends on many factors, including the type of asbestos fiber, level of exposure, duration of exposure, and the smoking history of the receptor (Krumm 2002; Yarborough 2006). Asbestos-related diseases may not appear until years after exposure and the latency period of asbestos-related disease ranges from ten to 40 years (EPA 1990a; Lange *et al.* 2006). Historically, asbestos exposure has been associated with occupational settings including construction sites, shipyards, railroads, manufacturing plants, and mines (ATSDR 1995a; EPA 1990a; Lange and Thomulka 2000; Yarborough 2006).

The most likely asbestos exposure during shingle recycling is through inhalation of fibrous dust. During the grinding process of shingle recycling, asbestos fibers may be released into the air. Because asbestos fibers are small and light, they can stay in the air for a long period of time (EPA 1990a). In addition, asbestos fibers cannot be broken down to other compounds in the environment and can remain in the environment for decades (ATSDR 1995a).

4.3 Asbestos-Related Regulations

Asbestos is regulated by the US Environmental Protection Agency (US EPA) and the Occupational Safety and Health Administration (OSHA); EPA regulates the handling and disposal of asbestos (through standards known as National Emissions Standards for Hazardous Air Pollutants (NESHAP)), and OSHA regulates occupational exposure to asbestos.

4.3.1 EPA

Asbestos was one of the first hazardous air pollutants (HAPs) regulated under Section 112 of Clean Air Act. In 1971, the EPA identified asbestos as a HAP, and the EPA first developed the NESHAP for asbestos in 40 CFR Part 61 in April 1973. The NESHAP for asbestos was revised in November 1990. The NESHAP provides standards for asbestos milling, manufacturing and fabricating operations, demolition and renovation activities, waste disposal issues, active and inactive disposal sites, and asbestos conversion processes. The NESHAP does not apply to residential jobs (structures with four or less dwelling units).

The asbestos NESHAP regulates the handling of asbestos-containing asphalt roofing products during demolition, renovation and disposal. NESHAP also regulates asbestos used in roadways In 40 CFR 61.143: “No person may construct or maintain a roadway with asbestos tailings or

asbestos-containing waste material on that roadway, unless, for asbestos tailings (a) It is a temporary roadway on an area of asbestos ore deposits (asbestos mine) or (b) It is a temporary roadway at an active asbestos mill site… or (c) It is encapsulated in asphalt concrete meeting the specifications contained in section 401 of Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects FP-35 1985, or their equivalent".

The asbestos NESHAP defines asbestos containing material (ACM) as any material containing more than 1% asbestos as determined using the method specified in Appendix A, Subpart F, 40 CFR Part 763, Section 1 (i.e., polarized light microscopy (PLM)). ACM is further characterized as either friable (a material that, when dry, can be crumbled, pulverized, or reduced to powder by hand pressure) or non-friable. NESHAP classifies non-friable ACM as Category I or Category II. Category I material is defined as asbestos-containing resilient floor covering, asphalt roofing products, packing and gaskets. Asbestos-containing mastic, which is commonly used as an adhesive or seal, is also considered a Category I material. Category II material is defined as all remaining types of non-friable ACM not included in Category I (EPA 1995).

The NESHAP specifically identifies several asphalt-containing roofing products that may also contain asbestos:

- Built-up roofing,
- Single ply membrane systems,
- Asphalt shingles,
- Underlayment felts,
- Roof coatings and mastics, and
- Base flashings.

The US EPA has issued interpretations of NESHAP as it relates to processors of asbestos-containing roofing products (Wilburn 1986). The interpretation indicated that the use of any asbestos-containing waste material as defined in 40 CFR 61.141 to surface any roadway is prohibited. The recycled material cannot be used on roadways if it is derived wholly or partially from asbestos-containing materials. The US EPA also determined that even though the presence of asbestos in asphalt shingles was in a non-friable state, the asbestos could become friable if subjected to processing (e.g., grinding), which causes this activity to be regulated by 40 CFR 61.152 and 61.156 which prescribes work practices to prevent airborne exposure to asbestos.

4.3.2 OSHA

Occupational exposure to asbestos is regulated by OSHA under standards 1910.1001 for general industry and 1926.1101 for construction work (OSHA 2002a). Under OSHA asbestos regulations, an employee cannot be exposed to more than 0.1 asbestos fibers per cubic centimeter for an average eight-hour workday. An employee must also not be exposed to more than one fiber per cubic centimeter in any given 30-minute period.

Section 1926.1101(g)(8)(iii) requires the employer ensure the following work practices are followed during the removal of asbestos-containing shingles (which includes asbestos shingles and asbestos-containing asphalt shingles):

- Cutting, abrading or breaking siding, shingles, or transite panels, shall be prohibited unless the employer can demonstrate that methods less likely to result in asbestos fiber release cannot be used;

- Each panel or shingle shall be sprayed with amended water (i.e., water that has had a surfactant or wetting agent applied to it in order to penetrate the ACM) prior to removal;
- Unwrapped or unbagged panels or shingles shall be immediately lowered to the ground via covered dust-tight chute, crane or hoist, or placed in an impervious waste bag or wrapped in plastic sheeting and lowered to the ground no later than the end of the work shift;

OSHA asbestos regulations include several other guidelines, including the methods used to measure asbestos levels and the protection that must be afforded to workers.

4.4 Asbestos Measurement Case Studies

Concerns over the presence of asbestos in asphalt shingles (especially discarded post-consumer asphalt shingles) has resulted in asphalt shingle recyclers being required to perform testing to evaluate whether asbestos is present in the shingle load they accept at their facility. As described previously, discarded post-consumer asphalt shingles tend to be much more heterogeneous than discarded post-manufacture asphalt shingles. As a result, there may be a greater likelihood for these discarded shingles to contain asbestos since there are unknowns about the composition, origin, and age of the material.

Asbestos sampling data from several asphalt shingle recyclers and recycling projects were collected and compiled to evaluate the frequency of asbestos detections. A summary of the data is presented in Table 3. Following Table 3 is a more detailed discussion of different asphalt shingle recycling case studies conducted throughout the US. In general, samples were taken at the facilities in Table 3 based on a "per load" basis and analyzed using PLM (i.e., EPA Method 600/R-93/116). It is noted that PLM is an analytical method that can provide asbestos measurement in bulk building materials. PLM is the most commonly used analytical method utilized by asphalt shingle recyclers since it is a quicker and less expensive method than transmission electron microscopy. Many facilities also collect samples of other roofing materials that may be present in the load (e.g., tarpaper); however, Table 3 only presents the results of asphalt shingle sample analyses. Recommended practices for establishing an asbestos sampling protocol can be found in Krivit and Associates (2007).

Table 3. Asbestos Testing Results for Waste Asphalt Shingles

State	Entity / Project	Sampling Dates	Number of Samples	# detected below 1%	# detected above 1%	Total % detected
Maine	Commercial Recycling	7/1994-10/1995	146	2	2	2.7%
Iowa	Central Recycling Inc.	9/1999-7/2001	1,791	0	0	0%
Florida	Roofs to Roads	8/2000-7/2001	591	3	2	0.8%
Missouri	United Methodist Church	7/2001	6	0	0	0%

Table 3 (continued)

State	Entity / Project	Sampling Dates	Number of Samples	# detected below 1%	# detected above 1%	Total % detected
Missouri	Peerless Landfill	06/2000	45	0	0	0%
Minnesota	Applied Environmental Sciences, Inc	01/2001-07/2002	206	1	0	0.5%
Massachusetts	ARI	6/2000-10/2001	2,288	11	1	0.5%
Massachusetts	P.J. Keating	10/2002	6	1	0	16.7%
Massachusetts	Rooftop Recycling, Inc	01/2006-03/2006; 5/2007-10/2007	6,461	0	2	<0.01%
Massachusetts	Recycle America Enterprises, LLC	12/2004-9/2007	16,154	0	401	2.5%
Totals			**27,694**	**18 (0.06%)**	**408 (1.47%)**	**1.53%**

4.4.1 Maine

Commercial Recycling Systems (CRS) of Scarborough, Maine has recycled asphalt shingles since 1994. In 1999 and 2000, the CRS processed over 10,000 tons of asphalt shingles. Asphalt shingles are collected at both municipal and commercial transfer stations and delivered in both roll-off and dump trailers to the CRS facility. All incoming loads are inspected to screen out wood, flashing, or other debris in the asphalt shingle loads. The shingles are then processed into the desired particle size and roofing nails are removed. During the processing, dust is minimized by using a water mist.

CRS tested 146 composite shingle samples for asbestos between 1994 and 1995. The sampling results indicated that four samples contained asbestos. Three of the detections were measured at levels of 15%, 8%, and less than 1%. One sample that showed a trace level of asbestos (< 1%) was identified as roofing material. All four detections were of the asbestos mineral chrysotile.

4.4.2 Iowa

Central Recycling Inc., a C&D debris recycler in Iowa, collected 1,791 random grab samples from various incoming loads of discarded post-consumer shingles. Collection and analysis occurred between September 1999 and July 2001. AMES Environmental Inc. utilized PLM to measure total asbestos. None of the 1,791 samples were found to have detectable levels of asbestos.

4.4.3 Massachusetts

Asphalt Reclamation Industries LLC, an asphalt shingle recycler in Massachusetts, tested incoming asphalt shingles on a per-load basis. The bulk of sampling occurred between June

2000 and October 2001. A total of 2,288 composite samples were taken from incoming loads and analyzed using PLM. Asbestos was detected in 12 samples, with 11 samples containing less than 1% asbestos and one sample containing 2% asbestos. Additionally, 110 tarpaper samples were analyzed and results indicated one detection of asbestos at a level of 5%. Furthermore, 25 ground (i.e., processed) shingles were sampled, and the results showed one sample with a trace amount of asbestos (< 1%).

Recycle America Enterprises, another asphalt shingle recycler in Massachusetts, tested 16,154 samples from incoming loads between December 2004 and September 2007. Detailed analytical reports between April 2005 and June 2006 were available; the remaining data was obtained from the recycler via a spreadsheet summary. All samples collected for analysis were analyzed using PLM and the samples were selected by an on-site asbestos inspector. Between April 2005 and June 2006, a total of 62 samples detected asbestos, of which 49 samples were shingles, 11 were tarpaper, and two were rolled roof materials (5,799 total samples collected between April 2005 and June 2006). Chrysotile was the asbestos fiber in all 62 detected samples, with levels mostly ranging from 2% to 5% and as high as 25%. Overall, there were a total of 401 asbestos detections during the approximate three year sampling period. According to asbestos testing personnel, the majority of the asbestos detections were caused by mastic that was attached to the shingle, and was not from the shingles themselves.

Roof Top Recycling Inc. processes over 20,000 tons of asphalt shingles per year. Asphalt shingle samples are collected and tested for asbestos on a per-load basis (approximately one test per 2.5 tons of incoming material). A minimum of one load per sample is collected, and additional samples are collected based on the discretion of the on-site asbestos inspector. A load may have additional samples collected if tarpaper or shingles with multiple layers are present. Available test data for 1,165 roofing shingle samples collected between January and March 2006 indicated one detection of asbestos (25% chrysotile). In the first and second quarter of 2007, a total of 15,192 tons of material were collected; a total of 5,296 samples were collected, resulting in one detection of asbestos. The processed shingles are typically used as an aggregate in concrete; however, a small amount is also used as part of an HMA mixture.

Data from another facility in Massachusetts provided by the company P.J. Keating indicated that one out of a total six samples of ground post-consumer waste asphalt shingles (as analyzed by PLM) contained a trace amount of asbestos (<1%).

4.4.4 Florida

Shingle testing was conducted between August 2000 and July 2001 as a part of the "Roofs to Roads" recycling project in Charlotte County (RMG 2001). Incoming loads were sampled by layer, meaning each qualifying load (i.e., a load with greater than 50% shingles by visual approximation) contained one or more layers of asphalt shingles and multiple samples were collected from each layer of each load. A total of six samples were collected from each layer of each load; four of the six samples (two asphalt shingle and two felt) were sent to the laboratory for analysis, and two of the samples (one shingle and one felt) were bagged and filed. A total of 591 samples were sent to the laboratory for analysis using PLM.

A total of six samples indicated asbestos levels greater than 1% (four were 3% chrysotile, one was 4% chrysotile and one was 5% chrysotile). However, four of the six detections of asbestos were attributed to other materials present in the sample. Three of the detections were caused by the presence of mastic on the asphalt shingle sample and one of the detections was caused by the presence of a silver material on the shingle. Seventeen samples were taken from ground

asphalt shingles and results showed none of the samples exhibited an asbestos content greater than 1%.

4.4.5 Missouri

Testing results were provided by the Missouri Department of Natural Resources, Division of Environmental Quality. Six asphalt shingle samples were collected in July 2001 and analyzed using PLM. The samples were collected from a Methodist church in Camdenton; no information was provided regarding the sampling methodology. Asbestos was not detected in any of the six asphalt shingle samples.

The Peerless Landfill also gathered 45 samples in June of 2000 using an unspecified collection method. The samples were analyzed by Precision Analysis lab. No asbestos was detected in any of the 45 samples.

4.4.6 Minnesota

Applied Environmental Sciences, Inc. analyzed 156 shingle samples and 50 tarpaper samples. Of the 156 shingle samples tested, none were found to have detectable levels of asbestos. One tarpaper sample detected asbestos above 1%. As recalled by inspectors and lab staff, the positive sample was collected from a commercial building with very old shingles.

4.5 Summary

Historical information indicates that asbestos was commonly used in the manufacture of several types of roofing material, including asphalt shingles, but information regarding the amount of asbestos that was used in asphalt shingles is limited. The potential for the presence of asbestos in asphalt shingles has somewhat hindered the widespread recycling of post-consumer asphalt shingles. Many states that allow asphalt shingle recycling require that shingle loads be tested to ensure no asbestos is present before allowing the recycler to process the material.

Data for over 27,000 asphalt shingle samples were evaluated. The results indicated that approximately 1.5% of the shingle samples analyzed indicated asbestos at detectable levels. However, it is noted that the cause of many of the asbestos detections were attributed to the presence of mastic and not the asphalt shingle itself. The low number of asbestos detections from the various case studies is consistent with the fact that the majority of asbestos-containing asphalt shingles ceased in the late 1970s or early 1980s, and that the typical lifetime of an asphalt shingle is approximately 12 to 25 years. Given that asphalt shingles are no longer manufactured with asbestos, one would expect that over time the amount of discarded post-consumer asphalt shingles to decrease even further.

5. PAH ISSUES

5.1 Environmental and Health Concerns With PAHs

Asphalt products in general, and asphalt shingles in particular, naturally contain PAHs because of the petroleum-based components that are used in the manufacture of asphalt. Because asphalt is an organic material derived from petroleum, it contains different types of hydrocarbons, including varying amounts of PAHs (Grosenheider et al. 2005; Wess et al. 2004). PAHs are a group of over 100 different chemicals consisting of carbon and hydrogen in fused-ring structures (ATSDR 1995b). PAHs are formed primarily during the incomplete burning of coal, oil and gas, or other organic substances (ARMA 1998). The environmental fate of most PAHs includes the release into the air, attachment to airborne particulate matter, and deposition onto the ground. In humans, PAHs are stored mostly in the kidneys, liver and fat. Many PAHs are harmless, but some may be reasonably expected to be carcinogenic. Laboratory testing on animals has resulted in tumors being formed upon ingestion, application to the skin, or inhalation of PAHs (ATSDR 1995b; Wess et al. 2004). In long-term PAH exposure scenarios, cancer, cataracts, kidney and liver damage, and jaundice may develop (ATSDR 1995b; Grosenheider *et al.* 2005). Recent research indicates that there may be an increased risk of cancer in workers exposed to PAHs (Levin and Jarvholm 1999; Posniak 2005). Epidemiological studies have indicated that the risk of developing lung, stomach and non-melanoma skin cancers increased in asphalt workers and roofers who were exposed to bitumen fumes (Levin and Jarvholm 1999; Partanen and Boffetta 1994; Posniak 2005). The EPA has identified seven PAHs that are probable human carcinogens, including benz[a]anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, dibenz[a,h]anthracene, and indeno[1,2,3-c,d]pyrene (EPA 2004).

Since PAHs are a naturally-occurring component of asphalt shingles, there may be a potential that human and/or environmental exposure to PAHs could be augmented as a result of recycling asphalt shingles, either through leaching after placement or through atmospheric emission during HMA production.

5.2 Leaching of PAHs

During the shingle recycling process, PAHs may potentially leach out either while stored/stockpiled or when reused in the various applications detailed in Section 2. Kriech et al. (2002) conducted a laboratory study that measured the total concentration of 29 different PAHs and the concentration of PAHs in leachate water (leached using the toxicity characteristic leaching procedure (TCLP)) of six virgin paving asphalt samples and four virgin roofing asphalt samples. The study evaluated three different analytical extraction procedures and ultimately, traditional liquid/liquid extraction was found to yield the best sample recovery. The roofing asphalt samples were obtained from a commercial built-up roofing manufacturer. The total PAH results indicated concentrations of the roofing shingles ranging from 4.0 to 23 mg/kg, while the paving asphalt sample concentrations ranged from 1.9 to 66 mg/kg. The leaching results indicated that all of the roofing samples were below the detection limit (0.1 mg/L) for all 29 PAHs. Two paving samples contained detectable amounts of naphthalene and phenanthrene; however, the levels were below drinking-water standards (Kriech *et al.* 2002).

CRS of Scarborough, Maine conducted sampling on waste asphalt shingles, analyzing the samples for a number of constituents (including the TCLP) for PAHs and total PAHs. The State of Maine requires asphalt shingle recyclers to obtain a license, and prior to approval of using

recycled asphalt shingles in an application other than in pavement (i.e., blending the shingles with aggregate as road base), testing must be conducted to compare chemical concentrations in the shingles to risk-based screening standards. The TCLP results indicated that the PAHs were not readily leachable. However, measurement of some carcinogenic PAHs exceeded the State of Maine's *de minimis* risk concentration for beneficial reuse application (Appendix A, Ch 418, Maine Solid Waste Management Rules), and therefore additional testing had to be conducted as part of the licensing process (CMRA 2007).

Testing of PAHs leaching from reclaimed asphalt pavement (RAP) has also been conducted. Brantley and Townsend (1999) performed a series of batch leaching tests on six samples of RAP collected throughout the State of Florida. The samples were leached using the TCLP, the synthetic precipitation leaching procedure (SPLP), and deionized water. The batch leaching tests accounted for dilution by utilizing a 20 to 1 liquid to solid ratio. Results for all batch leaching tests indicated that the RAP samples investigated were not a characteristic hazardous waste and none of the 16 PAHs were measured above the detection limit (Brantley and Townsend 1998). Brandt and DeGroot (2001) conducted static and dynamic leaching tests to evaluate PAH concentrations from ten asphalt samples, of which nine samples covered a representative range of commercially available bitumen products and one was made from one of the bitumen products. The results demonstrated that PAH concentrations in leachate from the ten samples were below the European Economic Community maximum tolerable concentration for potable water (0.1 µg/L) (Brandt and De Groot 2001).

Another assessment was made of the effects of runoff from asphalt pavement on streams in California. Water samples collected from water draining road surfaces were analyzed for PAHs and selected heavy metals (lead, zinc, cadmium). Results of the analyses indicated that concentrations of the PAH analytes in all stream and road runoff samples were below the detection limit of 0.5 µg/L (Wess et al. 2004).

5.3 PAH Emissions in HMA Production

5.3.1 Overview

Another potential environmental concern with the recycling of asphalt shingles is the emission of PAHs during the production of HMA. Since asphalt is a mixture of paraffinic and aromatic hydrocarbons, heating of asphalt can result in the emissions of PAHs (ARMA 1998; EPA 2000; Lee et al. 2004). It was reported by the EPA that PAHs are one of the major classes of air pollutants emitted from HMA facilities (EPA 2000). Based on an EPA emission assessment, approximately 13 lb of PAHs are emitted from a typical batch mix HMA facility with an annual production rate of 100,000 tons of HMA (EPA 2000). Lee et al. (2004) conducted a study to quantify PAH emissions from batch HMA plants. Gas samples were taken from batch mixers, preheating boilers, and discharging chutes. The reported PAH emission factor for batch mix plants were reported 139 mg/ton (30.6 lb per 100,000 tons) of product (Lee et al. 2004). It was also noted in the study by Lee et al. (2004) that approximately 90% of carcinogenic PAHs were removed by air pollution control equipment at the HMA plants studied.

While the quantity of PAH emissions from HMA facilities has been fairly well documented, the impact of using recycled asphalt shingles on PAH emissions is not well understood. A study is underway in Texas to evaluate the effect of recycled asphalt shingles on PAH emissions (and other constituents) during HMA production. Currently, there is no available data to suggest that emissions of PAHs at HMA facilities utilizing recycled asphalt shingles would be different than if

the facility did not utilize recycled asphalt shingles. It noted that on a life cycle basis, overall emissions may be reduced because of the energy offsets that using recycled asphalt shingles would provide versus using exclusively virgin asphalt materials.

5.3.2 Texas Case Study

A project underway in Texas includes an evaluation of the emission of PAHs from the processing of recycled asphalt shingles for the manufacture of HMA. Post-manufacture recycled asphalt shingles were authorized to be used in the production of HMA by the Texas Commission on Environmental Quality (TCEQ) in 2006. However, the use of post-consumer asphalt shingles was not approved, primarily because of the heterogeneous nature of discarded post-consumer asphalt shingles and unknowns related to possible asbestos content. The TCEQ has considered allowing the use of post-consumer asphalt shingles in HMA production; the allowance will be based on HMA facility stack testing results and a subsequent review of air quality impacts (Hyde 2006). The potential future use of post-consumer asphalt shingles depends on emissions stack testing of the following pollutants:

- Total VOCs,
- Speciated total PAHs (BTEX and naphthalene, anthracene, flouroanthene, methylpyrene, methylchrysenes, phenol, fluorene, formaldehyde),
- Particulate matter (silica, limestone),
- Total metals (silver, arsenic, cadmium, chromium, copper, nickel, lead, zinc), and
- Hydrogen chloride.

In addition to the testing of the above chemical constituents, the TCEQ indicated that before approving post-consumer asphalt shingles for use in HMA, the asphalt shingles must be tested for asbestos. As of June 2007, no data regarding PAH emissions from HMA manufacture containing recycled asphalt shingles had been collected.

5.4 Summary

One environmental concern with asphalt shingle recycling that has been raised by the regulatory community and others is the effect of the recycling of these materials on PAH emissions. PAHs are naturally occurring in asphalt products since asphalt products are petroleum-based. The pathways of concern that were evaluated included leaching of PAHs and the emission of airborne PAHs during HMA production.

The laboratory studies reviewed indicated that PAHs do not readily leach from different asphalt materials. TCLP results were obtained for virgin roofing asphalt samples and discarded asphalt shingle samples. The results indicated PAH concentrations were below the detection limit. The different studies evaluated indicated that PAHs do not readily leach, which is likely attributable to the low solubility of PAHs. Furthermore, a study that measured runoff from asphalt pavement in a stream resulted in PAH concentrations below the detection limit. Thus, it does not appear that the leaching of PAHs is a concern with regard to recycled asphalt shingles.

The emission of PAHs from HMA facilities has been well documented. The heating of the asphalt during production results in the release of the naturally-occurring PAHs within the asphalt. However, the contribution that discarded post-consumer or post-manufacture asphalt

shingles (as used in an HMA mixture) has on overall PAH emissions is unknown. There is at least one study that is evaluating this issue, but no known data have been collected to date.

6. SUMMARY

Currently, the majority of discarded asphalt shingles are sent to landfills, representing a significant fraction of the total C&D debris waste stream nationwide. The materials that comprise an asphalt shingle are considered to have promising recycling potential in applications such as road construction, road repair, and boiler fuel, among others. Recycling of asphalt shingles may provide an environmental benefit by offsetting the use of virgin asphalt in HMA production and by reducing the volume of debris disposed in landfills. Discarded asphalt shingles fall into two broad categories: post-manufacture (generally off-spec materials generated by an asphalt shingle manufacturer) and post-consumer (generated through construction activities). The recycling of post-manufacture asphalt shingle waste has been more widely accepted than post-consumer asphalt shingle waste because of its relatively homogeneous nature. Post-consumer asphalt shingle recycling has been found to be technically feasible, but the practice has been limited in some areas because of concerns associated with the presence of asbestos (and to a lesser extent, concerns regarding PAH compounds).

An objective of this white paper was to provide a review of environmental concerns associated with asphalt shingle recycling. As part of this analysis, a review of existing asphalt shingle sample analytical data for asbestos was conducted, manufacturer's literature on asbestos use was evaluated, and pertinent literature and regulations were highlighted. The following are the most notable observations from this analysis.

6.1 Asbestos

- Asbestos was used in the manufacture of asphalt shingles and asphalt-containing roofing materials as far back as the late 1800s, and continued to the early 1980s.
- Data on the amount of asbestos used in the manufacture of asphalt shingles is very limited; information on one type of asphalt shingle manufactured between 1907 and 1979 indicated that between 35 and 50% asbestos was used.
- The typical service life of asphalt shingles generally varies between 12 and 25 years, but since it is common practice in re-roofing to install new shingles directly on top of old ones, a load of post-consumer asphalt shingle waste may contain multiple layers of asphalt shingles of varying age.
- Analytical results for over 27,000 asphalt shingle samples collected at various facilities in the US indicated that approximately 1.5% of all samples contained enough asbestos to be considered an ACM (i.e., >1% asbestos). Many of the asbestos detections were caused by other materials such as mastic that were attached to the asphalt shingle samples.
- Effective sourcing procedures for non-contaminated asphalt shingles will likely result in reduced detection of asbestos in asphalt shingle samples, since non-shingle roofing products such as mastic and tarpaper may contain asbestos. Some states have restricted post-consumer shingle processing to include only shingles manufactured for residential homes.

6.2 PAHs

- Because of their low solubility, PAHs are not expected to leach from the solid phase into the liquid phase to a large extent. Although minimal data have been reported for PAHs leaching from asphalt shingles, one leaching study on discarded asphalt shingles found that PAHs did not readily leach. Related studies on virgin roofing asphalt, reclaimed asphalt pavement, and run-off from asphalt pavement have found PAH concentrations are typically leachable at very low levels, often below the laboratory detection limit.
- Based on analytical results that measured total carcinogenic PAHs, the State of Maine requires users of recycled asphalt shingles to obtain a license prior to reusing the material.
- PAHs are emitted during HMA production. HMA facilities are required to have a permit that limits the amount of PAHs that the facility can emit. The effect of using discarded post-consumer asphalt shingles in HMA on PAHs is unknown. It is not anticipated that the use of clean, well-sourced post-consumer asphalt shingles will cause an undue increase in PAH emission during HMA production.
- Recycling of post-consumer asphalt shingles has been limited in some cases (e.g., in Texas) because of unknowns related to the impact of using post-consumer shingles in HMA production (in terms of PAH emissions). Currently, no data have been reported on whether there is an impact on PAH emissions at HMA facilities using post-consumer asphalt shingles.

7. RECOMMENDATIONS

The review of existing and available information conducted for the development of this white paper suggests that recycling of asphalt shingles, especially as a component of HMA, is technically feasible and is likely to offer economic and environmental benefits. The information gathered also suggests that the occurrence of asbestos in tear-off shingles from residential reroofing projects will be limited, but that the recycling facility operator should expect to encounter ACM on occasion and thus should be adequately prepared to monitor and manage such debris. Environmental risks associated with PAH migration appear to be small and comparable to that presented by any asphalt-containing material. The data do not exist at the current time to suggest that post-consumer asphalt shingle recycling into HMA should be limited because of concerns of PAHs; for other recycling applications where the shingles are applied directly to the environment, PAH risk should be evaluated within the context of existing waste beneficial use programs.

Regulatory agencies are faced with the challenge of developing and administering regulations, policies and permit conditions that provide for protection of human health and the environment at recycling facilities and with respect to the use of the recycled products. Given the environmental benefit of recycling, these requirements should be adequate for the risk presented and not unnecessarily conservative, and thus inhibitory of the recycling enterprise.

Based on our review of the existing information, and how some regulatory agencies and recycling facility operators are managing the risks and benefits associated with this process, the following technical guidelines are recommended for consideration as components in a facility's operations permit.

1. **An Operations Plan:** The operations plan should include the following elements.
    a. Drawings showing the layout of the facility, including locations of staging and storage areas and equipment. Limitations on the size of unprocessed and processed material piles should be identified.
    b. A description of how clean asphalt shingle will be sourced. This may include the steps taken to communicate to haulers/contractors that loads with contaminants will not be accepted. Additionally, the plan should include steps that will be taken to communicate with haulers/contractors if they bring unacceptable materials to the facility to prevent future delivery of unacceptable materials.
    c. A description of the waste screening and identification plan. There should be a demonstration that personnel inspecting the loads will be trained to identify asbestos and asbestos-containing materials and that this inspector will be on-site at all times that waste is received if the facility is accepting or processing asphalt shingles.
    d. A health and safety plan that includes an element of asbestos training for all employees (along with training on other appropriate risks as part of operations).
    e. A description of methods to control storm water run-on and run-off.
    f. A description of methods to control dust.

g. A description of how the asphalt shingles will be processed. This will include providing drawings of the process train, separation equipment, location(s) of waste screeners or spotters, and processing equipment.

h. A procedure for maintaining all documentation of incoming materials (tonnage and source), inspection records, sampling history, analytical results, and outgoing finished product (tonnage and end user) to allow review during inspections.

i. Identification of routine reporting frequency of asbestos testing results to the regulatory agency. Some states (e.g., Wisconsin) have required annual reporting of asbestos testing results.

2. **A Monitoring and Production Quality Assurance Plan**. This plan should include the following elements:

a. The methods used by the facility to check incoming asphalt shingle-containing loads.

b. The frequency for sampling loads. Loads that have suspected ACM (as identified by the trained asbestos inspector) should be either turned away or segregated and sampled. The load should not be processed until the laboratory results come back, and should only be processed if the material contains <1% ACM.

c. The protocol for determining the number of samples once a load has been identified as potentially having ACM. The sampling protocol should follow standard, established procedures (e.g., ASTM standards D 6009-96; D6044-96; D 6051-96; D 4687). At a minimum, one sample of each type of roofing material in the load should be taken.

d. Identification of a certified laboratory that will conduct the asbestos measurement in accordance with the appropriate analytical method (e.g., PLM or TEM).

e. A protocol for random sampling of incoming asphalt shingle waste loads. The protocol should identify the sampling frequency and the number of samples taken during each sampling event. Sampling frequency may need to be periodically adjusted based on sample analysis results; the adjustment in sampling frequency may be recommended by the facility owner/operator or the regulatory agency.

f. A. protocol for random sampling of the processed or finished asphalt shingle product prior to end use. Guidance on finished product sampling frequency has been provided elsewhere (Krivit and Associates 2007).

g. Identification of a protocol for managing the load if the laboratory analysis results indicate ACM >1%. If the laboratory results show that ACM is <1%, then the load may be processed as usual.

h. Provisions for materials acceptance in the event that a contractor conducted asbestos sampling of a load of asphalt shingles or roofing materials prior to delivery of the load to the processing facility. The sampling and analysis conducted by the contractor must be in accordance with the appropriate ASTM

and EPA methods described above, and the asphalt shingle recycler must obtain documentation demonstrating this from the contractor.

i. If the processing facility desires to conduct asbestos analysis on site, the facility owner/operator should provide documentation for properly establishing an on-site laboratory that meets the requirements for PLM or TEM analysis.

3. **An End Use Plan**. As part of the operations plan, the operator must identify what the final use of the processed product will be.

    a. If the material will be used in an **asphalt matrix** (e.g., in HMA):

        i. The processed asphalt shingle material should be sent to a facility that is permitted to accept such a material.

        ii. No additional restrictions are recommended.

    b. If the material will be used in a **non-asphalt matrix**:

        i. The operator should go through their state's beneficial use determination guidelines (or equivalent) for asphalt shingles to assess the potential exposure risk of the material.

        ii. If beneficial use determination rules specific to asphalt shingles do not exist in the state, seek guidance from the regulatory agency's contact for beneficial use determinations to evaluate the appropriate beneficial use guidelines that should be followed.

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