



The Bitumen Roofing Industry – A Global Perspective:

Production, Use, Properties, Specifications and Occupational Exposure

Prepared by

The Asphalt Roofing Manufacturers Association

The Bitumen Waterproofing Association

The National Roofing Contractors Association, and

The Roof Coatings Manufacturers Association

Second Edition

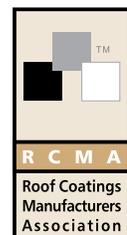
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This review was prepared by the Asphalt Roofing Manufacturers Association (ARMA), the Bitumen Waterproofing Association (BWA), the National Roofing Contractors Association (NRCA), and the Roof Coatings Manufacturers Association (RCMA), to provide a general information resource for employees, customers and others interested in the bitumen roofing industry and potential exposures to bitumen fumes. It presents broadly representative descriptions and summaries of the industry's products, operations and associated exposures, based on information that is published in the open literature or otherwise readily available to the general public and believed to be reliable. The reader is advised that, particularly because of the complexity of bitumen and the operations in which it is used, the general descriptions and summaries presented here may not be applicable to a specific business, product or operation, past or present. Although every reasonable effort has been made to be thorough and accurate in preparing this review, the sponsoring organizations cannot accept responsibility for any inaccuracies it may contain.

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Executive Summary

The global bitumen roofing industry, which consumes about ten million metric tons of bitumen per year worldwide and produces more than six billion square meters of roofing annually in Europe and North America alone, encompasses a broad range of products and application practices. Like bitumens used in other industries, bitumens used in roofing are engineering materials made to meet varying physical properties suited to disparate commercial applications. Thus, bitumen roofing products are made from lower-softening-point straight run bitumens and from oxidized bitumens that have been processed along an extensive range of softening points. Straight-run and air rectified bitumens are used to make polymer modified bitumen products as well as underlayments and liquid roofing products such as coatings and cements. Oxidized bitumens processed to higher softening points are used to make roofing shingles, roofing membranes and built-up roofing systems. Other roofing products require bitumens with different physical properties calling for still other levels of oxidation.

When bitumen is heated above its softening point, bitumen fumes (aerosols, vapors, gases) are released. Temperature has a significant impact on fume emission rates. Differences in crude sources, bitumen manufacturing processes, application practices, physical properties, and ambient weather conditions also affect either emission rate or exposure to the fume. Because bitumens are made to a wide range of softening points, they respond much differently to temperature. It is incorrect, therefore, to assume that the fume emission rates of higher-softening-point bitumens are substantially greater solely because higher temperatures are needed to reduce their viscosities to levels suitable for commercial operations. But while temperature is not a sufficient indicator of the relative fuming potential of bitumens with dissimilar physical properties, there is no doubt that, for any one bitumen, lower temperatures mean less fumes.

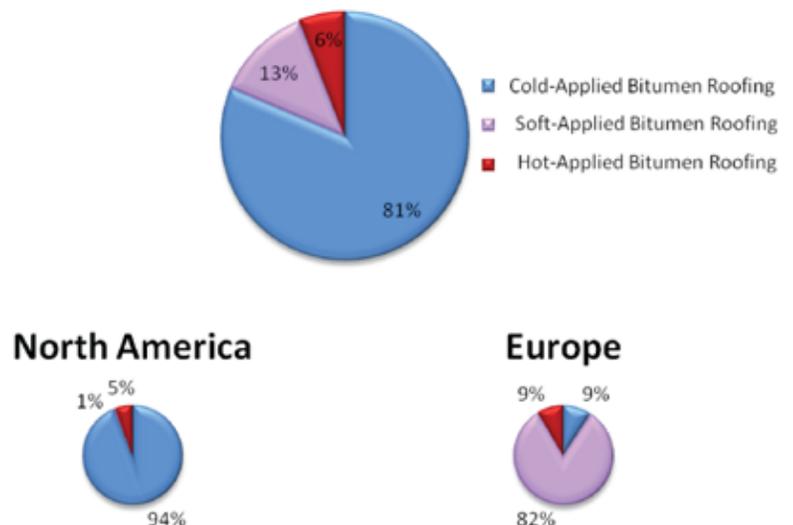
Bitumen roofing products and systems can be cold-applied (i.e., put down at ambient temperatures without heating), soft-applied (i.e., heated with torches or hot air welders sufficiently to ensure good adhesion to the substrate), or hot-applied (i.e., by applying hot liquid bitumen as the bonding agent). The installation of

cold-applied products – such as bitumen shingles, some polymer modified bitumen roof systems, and all cutback and emulsified bitumen roofing products – generates no bitumen fumes at all. Likewise, the available exposure data for soft application methods used for many polymer modified bitumen products indicate, as expected, that worker fume exposures are well below those seen in hot-applied roofing bitumen operations.

Hot-applied products were prominent for much of the 20th Century, but as shown in Figure 1, cold- and soft-applied products and systems are the face of the bitumen roofing industry today:

- Cold-applied bitumen shingles dominate the steep-slope (principally residential) roofing market in North America.
- In Europe, soft-applied products such as polymer modified bitumen membranes have almost as strong a position in the low-slope or “flat-roofing” (principally commercial and industrial) segment of the market.
- On both continents, the past 20 years have seen a sharp decline in the use of hot-applied low-slope roofing systems which, today, account for just 6% of the bitumen roofing produced.

Figure 1:
NA/EU Bitumen Roofing Production by Application Temperature



Source: Table 1

While some bitumen roofing is used in other parts of the world, the largest volumes are in Europe and North America and the practices and products in other parts of the world tend to follow the European and North American models.

Consequently, the principal areas of interest on the matter of worker exposures to bitumen fumes in the roofing industry are in manufacturing plants, where the use of hot liquid bitumen is necessary to the production process, and in the small and declining portion of construction jobs where hot application methods are used. As a result of product innovation, improved process emission controls and the widespread use of closed systems, fume exposures in manufacturing have fallen dramatically over the last 30 years and are typically below current health-based limits. In the declining hot-application segment of the market,

Government/Labor/Industry collaborative investigations have identified product, equipment and work practice controls that can significantly reduce worker fume exposures.

Exposures to other substances occur in any construction trade. Perhaps the most important of these for roofing workers are two materials that were once widely used in roof construction: asbestos, which is no longer used on either continent except for a minor use in certain liquid adhesives in the U.S., and coal tar, which is no longer used in Europe and retains just 1% of the North American low-slope roofing market primarily due to government building specifications. Nevertheless, the potential for exposure continues, primarily because of particulates created during tear-offs of previously installed roofs.

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1. Bitumen Use in the Roofing Industry

The term “roofing bitumen” is essentially archaic, a vestige of the industry as it existed prior to 1980. The terms “roofing bitumen” and “oxidized bitumen” are often used interchangeably in the literature and are sometimes even defined as synonymous. For example, the definition of “oxidized bitumen” in the current International Agency for Research on Cancer (IARC) Monograph for Bitumens [IARC 1985] contains this statement: “In the USA, bitumens produced using air blowing are known as air-blown asphalts or roofing asphalts” More recently, a review by the National Institute for Occupational Safety and Health [NIOSH 2000] broadly defines “roofing asphalt” as “asphalt that is refined or processed to meet specifications for roofing,” but characterizes “roofing asphalt” on the basis of scientific data relating specifically to hot-applied built-up roofing (BUR), an oxidized bitumen product that is just one of the diverse types of bitumen-based products used in the roofing industry. “Roofing bitumen” is defined or treated as synonymous with oxidized bitumen in many other publications; examples include Bingham [1981], Emmett [1986], EPA [1991, 1994a], CONCAWE [1992], and Sivak [1997].

As discussed below, today’s global bitumen roofing industry encompasses a broad range of products that (i) have markedly different physical properties, (ii) are made using straight run bitumens and bitumens that have been oxidized to varying degrees, depending on the physical properties sought for the end product, and (iii) are installed using a variety of cold, soft and hot application methods. In short, the term “roofing bitumen” is largely meaningless and, if used to denote the hot-applied products that characterized the industry decades ago, misleading and erroneous. The many different types of bitumen used in current-day roofing exhibit dramatically different fume exposure potential and, as a group, cannot fairly be characterized on the basis of any one type of bitumen, or any one set of application temperatures or practices.

1.1 Bitumen Roofing Products

Bitumen manufacturers estimate that, globally, roofing accounts for about ten million metric tons, or about ten percent, of worldwide consumption of bitumen [AI 2011]. Because the physical properties of bitumen make it an attractive option in roofing applications, it has long been used in a wide variety of products and systems. Today, these products include those cold-applied at ambient temperature, those applied after softening the material sufficiently to ensure good adhesion to the roof substrate, and those using hot liquid bitumen to laminate the elements of the roof system. The shares of these three types of systems in the North American and European bitumen roofing markets are shown in Table 1. The principal reason for the differences between North America and Europe is that, while shingle manufacture for the steep-slope roofing market accounts for a large share of North American production, bitumen shingles are of minor importance in the European roofing manufacturing industry. See Table 2. The principal products manufactured on both continents are described in the following sections.

Table 1
2006 North American and European Bitumen Roofing Production, Stratified by Application Temperature*

	<u>North America</u>		
	<u>Cold-Applied Products</u>	<u>Soft-Applied Products</u>	<u>Hot-Applied Products</u>
Shingles	3403	0	0
Built Up Roofing	39	0	259
Bitumen Membranes & Underlayments	1418	0	0
Polymer Modified Bitumen Roofing	235	35	39
Total	5095	35	298
Market Shares by Application temperature	94%	1%	5%
	<u>Europe</u>		
	<u>Cold-Applied Products</u>	<u>Soft-Applied Products</u>	<u>Hot-Applied Products</u>
Shingles	40	0	0
Built Up Roofing	0	0	2
Bitumen Membranes & Underlayments	14	256	14
Polymer Modified Bitumen Roofing	32	514	64
Total	86	770	80
Market Shares by Application temperature	9%	82%	9%

* All figures are millions of square meters (M m2) of roofing produced. Equivalent values for roof area coverage are lower by factors that differ according to specific products or systems depending on the overlap used in installation and the number of layers or plies.

Source: Appendix B

1.1.1 Bitumen Roofing Shingles are the principal roofing products used on steep-slope structures in North America. They are a minor product in the European steep-slope, or pitch roof market. Today, bitumen shingles are typically made by coating a glass fiber mat with a mixture of oxidized coating bitumen and limestone mineral filler. The coating bitumen used in fiberglass shingle manufacture is typically oxidized to a softening point (S.P.) range of 90-110°C. Colored mineral granules are usually embedded in the surface of the filled bitumen. They are cut in rectangular shapes and in many cases laminated in multiple layers to achieve desired aesthetics. Bitumen shingles can also be made by saturating organic felts with an oxidized saturant bitumen (S.P. 45-60°C) and then coating the felts with filled oxidized coating. This type of product, which once dominated the shingle industry, has been almost entirely replaced by shingles made with glass fiber mats. As discussed later in this paper, this transformation has played a significant role in the sharp decline in worker bitumen fume exposures in shingle manufacturing plants. Bitumen shingles are durable solid materials that are installed over a bituminous felt-based or peel-and-stick underlayment in an overlapping manner that sheds water (Figure 2). They are applied “cold” – that is, without heating – using mechanical fasteners (nails, staples)

1.1.2 Polymer Modified Bitumen Membranes are typically made by mixing thermoplastic polymers with straight-run or oxidized bitumen and a mineral filler, and then coating a fiberglass or polyester mat or other reinforcements with the mixture. When oxidized bitumens are used in the manufacture of these products they are typically softening points less than 50°C, in the range of air rectified bitumens [AI 2011]. Thus, the coating may be an air rectified bitumen or a blend of a higher-softening-point oxidized bitumen with a lower-softening-point material to achieve the properties of an air-rectified bitumen. Waterproofing systems made with these products consist of one or more polymer modified bitumen sheets and an underlying base sheet or the manufacturer’s approved substrate, all of which are laminated together at the construction site. The polymer modifier used in these systems may be either atactic polypropylene (APP) or styrene-butadiene-styrene (SBS) block copolymer, or other polymers within the same chemical families.

Table 2
2006 North American and European Bitumen Roofing Production, Stratified by Type of Roof *

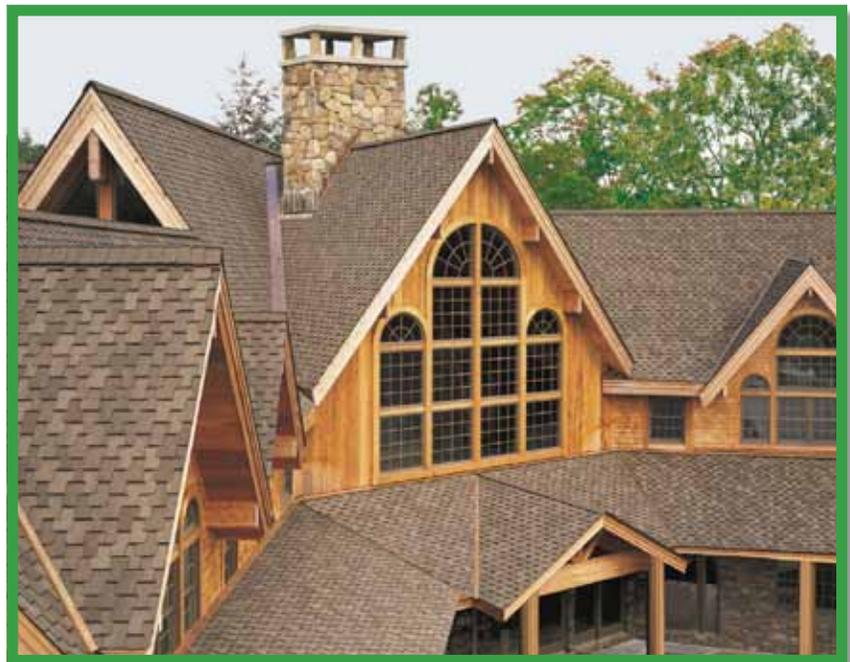
<u>North America</u>		
	<u>Steep-Slope Roofing</u>	<u>Low-Slope Roofing</u>
Shingles	3403	0
Built Up Roofing	0	298
Bitumen Membranes and Underlayments	1418	0
Polymer modified Bitumen Roofing	0	309
Total	<u>4821</u>	<u>607</u>
Market Shares by slope	<u>89%</u>	<u>11%</u>

<u>Europe</u>		
	<u>Steep-Slope Roofing</u>	<u>Low-Slope Roofing</u>
Shingles	40	0
Built Up Roofing	0	2
Bitumen Membranes and Underlayments	14	273
Polymer modified Bitumen Roofing	0	610
Total	<u>54</u>	<u>885</u>
Market Shares by slope	<u>6%</u>	<u>94%</u>

* All figures are millions of square meters (M m2) of roofing produced. Equivalent values for roof area coverage are lower by factors that differ according to specific products or systems depending on the overlap used in installation and the number of layers or plies.

Source: Appendix B

Figure 2 Cold-Applied Bitumen Roofing Shingles



Polymer modified bitumen membranes are applied to low-slope roofs in three ways:

1. As illustrated in Figure 3, SBS-based and APP-based systems can be cold-applied by using a solvent-borne adhesive to bond the membrane into the roof system without heating. In addition, increasingly popular “peel-and-stick” polymer modified bitumen products are made with self-adhering surfaces that bond the membrane directly to the substrate with no heating (Figure 4). These products are typically made by impregnating a fiberglass or polyester mat or other reinforcements with a polymer-modified, mineral filled bitumen and applying sand or slate on the top side and a plastic film or sand to the other. Membranes used for peel and stick application contain a resin which is added to the bitumen mass for adhesion purposes. In the case of a peel and stick membranes, a release paper on the bottom side protects the adhesive prior to application.

2. Both SBS and APP systems can be “soft-applied” by heating small sections of the back side of the sheet and the substrate with propane-fired torches or specially designed hot-air welders just before that section is applied to the roof. The heat is applied only as needed to ensure adhesion of the polymer modified bitumen membrane to the substrate. See Figure 5.

3. SBS-based polymer modified bitumen membranes can be hot-applied using an oxidized bitumen or a polymer modified bitumen made with styrene-ethylene-butylene-styrene (SEBS) block copolymer. The hot bitumen can be mopped or poured into place, or applied with a mechanical spreader or felt-laying machine (shown in Figure 7 below applying BUR).

Application of these products can include composite systems. For example, in Compact Roof Systems built in Europe, polymer modified bitumen roof membranes are soft-applied onto temperature-resistant insulation boards that have been dipped in liquid hot bitumen and adhered directly to the roof substrate.

1.1.3 Oxidized Bitumen Membranes: These products are typically made by coating a fiberglass or polyester mat or other reinforcements with a mixture of oxidized bitumen (typical S.P. 70-110°C) and limestone mineral filler, and then packaging the finished product in rolls. These products may be made with a mineral granule surface and are called roll roofing in North America. Roll roofing products are used in lower-slope sections of the roofing market, and are applied at ambient temperatures without heating. In Europe most oxidized bitumen membranes are soft-applied and either used as underlayments for other roofing products, such as slate or clay tile roofs, or as parts of other roofing systems.

Figure 3 Cold Application of a Polymer Modified Bitumen Membrane Using an Unheated Liquid Roofing Adhesive



Figure 4 Application of a Peel-and-Stick Polymer Modified Bitumen Membrane



Figure 5 Soft Application of a Polymer Modified Bitumen Membrane Using a Propane Torch



1.1.4 Bitumen Felt Underlayments are used in the construction of shingle, shake and tile steep-slope roofs (Figure 6). These products are usually made by saturating organic or inorganic felts with straight-run or oxidized saturant (typical S.P. 40-50°C) which may or may not be mineral filled. They are applied using mechanical fasteners such as nails.

1.1.5 Built-Up Roofing (BUR) systems are made by laminating (or “building up”) successive layers of waterproofing sheets in place on a low-slope roof (Figure 7). BUR products and application practices differ in certain respects between North America and Europe.

In North America, the waterproofing sheets are manufactured by impregnating and coating a fiberglass mat with oxidized bitumen, with or without a mineral filler. On the roof, BUR systems are usually hot-applied, using heated oxidized bitumen or, much less frequently, SEBS modified bitumen, to bond the elements of the system together. BUR systems can also be cold-applied by using either bitumen emulsions or bitumen cutbacks to laminate the sheets without heating. BUR systems may be finished with a variety of top surfaces including: (1) a flood coat of hot oxidized bitumen with aggregate, (2) a capsheet made from oxidized bitumen or a polymer modified straight-run bitumen, or (3) a cold-applied solvent- or water-borne liquid bitumen coating. In North America a very small amount of BUR bitumen is used to hot mop fleece backed EPDM (ethylene propylene diene monomer) rubber membranes.

In Europe limestone-filled oxidized or polymer modified bitumen is poured directly on the substrate. A fiberglass or polyester mat or other reinforcement is added to the top of the hot bitumen layer, followed by another layer of bitumen (polymer or oxidized). The system is topped with sand or slate. Cold adhesives are not used in making BUR systems in Europe.

Table 3 describes the four types of oxidized BUR bitumen recognized in North American product nomenclature, which have softening points and application temperatures that increase in step with the slopes of the roofs to which each type applies. Type I is the softest (least viscous) grade and is used on very low-slope roofs at the lowest recommended application temperatures for BUR systems. Type IV is the hardest (most viscous) grade and is used on the highest slope roofs suitable for BUR systems. Type III is the most common BUR system. North American BUR specifications are not used in Europe. In addition, Europe does not have a BUR product with the physical properties and roof applications corresponding to Type I BUR as defines in North American specifications.

Figure 6 Cold-Applied Bitumen Felt Underlayment



Figure 7 Hot Application of a Bitumen Built Up Roofing Membrane Using a Felt-Laying Machine



1.1.6 Liquid Bitumen Products:

A wide variety of liquid to semi-solid products are made by mixing fibers, fillers and sometimes polymers or aluminum flakes with either bitumen cutbacks or emulsions. Both straight-run and oxidized bitumen are used, with softening points varying according to the properties desired for the end-product. These products are used in roofing as well as a number of other operations such as waterproofing, dampproofing, rust-proofing (including undercoating), sealing (including driveways and parking lots), and crack and joint filling. In roofing they are used in a large number of products that can be classified into separate commercial groups representing different physical and performance characteristics and uses. The principal groups are coatings (including reflective aluminums), sealers, adhesives, cements, caulks and primers. As used in roof construction, maintenance and repair, all of these products are cold-applied.

1.2 Production and Use

Despite the many choices of material available for roof construction, bitumen has for nearly a century been a mainstay in the roofing industry in both the U.S. and Europe. In the rest of the world, the products developed in Europe and North America have gained some acceptance, but the volumes in Europe and North America still are orders of magnitude higher than in the rest of the world – hence the focus on these two regions in this review.

The idea of using a bitumen-like binder to coat roofing felt was first published in a paper given to the Royal Swedish Academy of Sciences in 1784. By 1870 several types of machines existed to manufacture rolls of roofing felt in Europe. In North America, bitumen has been used to make roofing products since the late 1800s, when the first bitumen-based built-up roofing (BUR) system was introduced.

During the 20th Century, the number of uses the roofing industry has found for bitumen has multiplied, and bitumen has become the foundation of many of the most popular roof systems in the North American and European markets. The

Table 3
North American Specifications for Oxidized Built-Up Roofing Bitumen

BUR Type	Highest Roof Slope Suitable for Use	Softening Point	Typical Recommended Mop Application Temperature ^(b)
Type I (Dead Level) ^(a)	2%	57-66°C	160-200°C
Type II (Flat)	4%	70-80°C	175-204°C
Type III (Steep)	25%	85-96°C	210 -230°C
Type IV (Special Steep)	50%	99-107°C	220-240°C

Source: ASTM D 312, Owens Corning

(a) BUR bitumens with Type I specifications are not used in Europe.

(b) Values refer to the equiviscous temperature (EVT), the temperature at which the viscosity of the asphalt, when applied, will result in a quality roofing system. EVT is measured in the mop bucket just prior to application. There are also EVT values for mechanical application which are typically 10 to 20C higher than mop EVTs. Because of heat loss during transport, bitumen temperatures in the heating vessels (kettles, tankers) are higher.

principal trends of the major systems are reviewed in the next two sections.

1.2.1 Steep-Slope Roofs: Steep-slope roofs have slopes greater than 14 degrees. They are found primarily on residential buildings such as single family homes, attached townhouses and apartment complexes. Certain commercial structures – e.g., some shopping centers as well as some office buildings and complexes – also have steep-slope roofs.

Bitumen shingles were introduced in the early 1900s in North America and rapidly became the product of choice for residential roofs, replacing roll roofing. Today they make up 83% of the steep-slope market in North America [3M 2007]. The volume of shingles produced and applied has also increased steadily over the last 40 years as the number of homes has increased. During the same time period, and especially over the past 20 years, the industry has been transformed from one that was based on an organic felt to one based on fiberglass mat. Figure 8 shows both the completeness of this transformation and also the significant growth of the overall demand for bitumen shingles [ARMA 2007]. In the same time period a similar transition from organic to inorganic mats took place in Europe for shingles and oxidized bitumen membranes. In contrast to North America, bitumen shingles have never gained a substantial foothold in Europe, where they hold less than 5% of the steep-slope roofing market [BWA 2007].

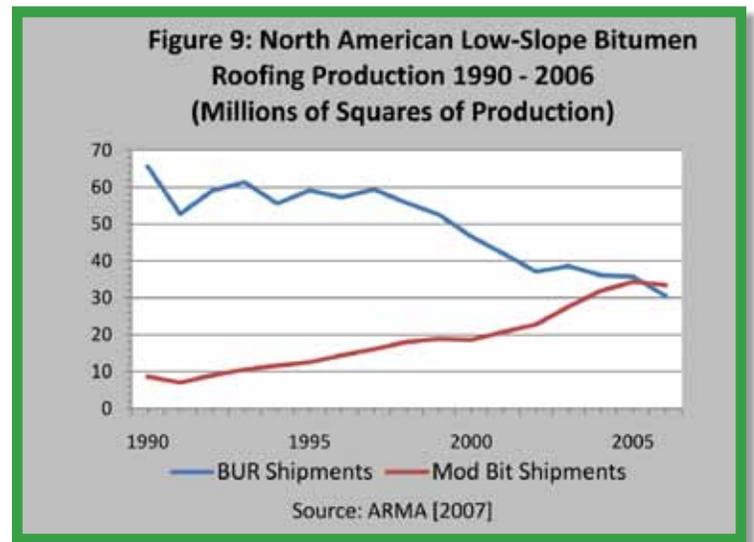
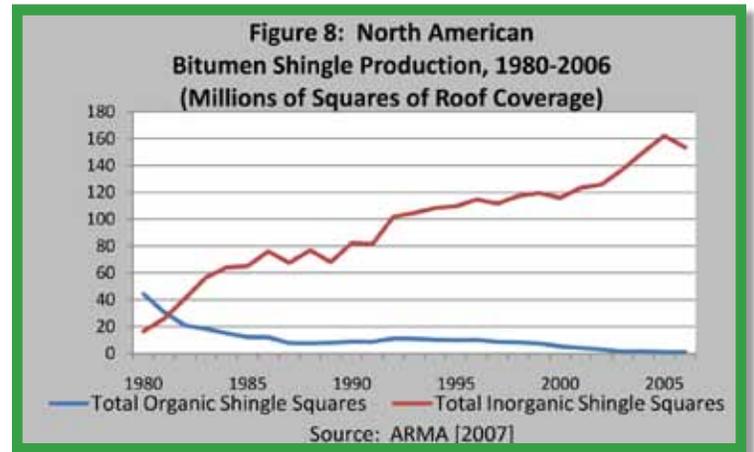
1.2.2 Low-Slope Roofs: Low-slope roofs have slopes of less than or equal to 14 degrees and are sometimes called “flat roofs.” Low-slope roofs are found on commercial, industrial and government buildings, including military bases, as well as high-rise apartment/condo buildings, hospitals, and schools. They can also be found on single family residential homes. Bitumen is used in two different low-slope roof waterproofing systems that are popular today: polymer modified bitumen membranes and built up roofing systems. In the United States, these two systems hold 35 to 40% of the low-slope market. Polymer modified bitumen membrane systems hold 19% of new construction and 22% of reroofing markets, compared to 16% and 17% respectively for built up roofing systems [NRCA 2007a]. The total share of low-slope bitumen systems is even higher in Western Europe where polymer modified bitumen systems dominate the low-slope bitumen market [BWA 2007].

Built-up roofing systems were originally introduced in the late 1800s and for much of the 20th Century were the dominant product in the low-slope commercial and industrial roofing market. Over the last few decades both continents have seen a steady decline in hot applied bitumen BUR systems, accompanied by a corresponding increase in the use of polymer modified bitumen systems. This transformation is virtually complete in Europe, where traditional hot-mop BUR systems have nearly disappeared from the marketplace. In Europe today, the use of hot bitumen is limited to the installation of some oxidized bitumen membranes and certain insulation products, as in the specialty Compact Roof Systems mentioned above [Rühl 2006]. In the U.S., as shown in Figure 9, production of bitumen BUR sheets has declined steadily over the past 10 years as sales of polymer modified bitumen sheets have risen [ARMA 2007].

1.3 Production Facilities and Employment

1.3.1 Manufacturing: According to industry data reported by NIOSH [2001], approximately 3000 to 4000 United States roofing manufacturing workers are exposed to bitumen fumes in approximately 100 plants. There are about 120 bitumen roofing manufacturing plants in Europe employing roughly 3000 workers [BWA 2007].

1.3.2 Contractors: As explained in Appendix E [Shanahan 2008], there are about 19,000 roofing contractor firms and 51,000 sole proprietorships in the U.S., employing an estimated 236,000 workers. Excluding white collar workers and helpers unlikely to be significantly exposed in roofing operations, about 174,000 workers are engaged in roof construction, repair, maintenance or removal operations.



An estimated 99,000 of these roofers work primarily in the low-slope sector of the roofing market where hot- and soft-applied bitumen roofing systems (in addition to a number of non-bitumen systems) may be installed. NRCA estimates [Shanahan 2008] that about 7% of total U.S. roof construction, repair, maintenance or removal hours involve installation of hot-applied bitumen roofing systems, and an additional 2% involve soft-applied systems. Although specialization in hot-applied systems such as BUR was once relatively common, the past two decades have seen a strong trend toward diversification as low-slope commercial/industrial contractors and their workers have sought to expand their capabilities to include other roofing products and systems. As a result of the marked decline in BUR-specialization, while it is clear that roofers who work on hot asphalt jobs represent a relatively small fraction of the overall population of low-slope roofers, it is no longer possible to identify or

quantify a significant subpopulation of contractors and workers that are exclusively or primarily engaged in hot-applied bitumen roofing work. In addition, while it was not uncommon during much of the 20th Century for many BUR workers to maintain considerable longevity (20-30 years) in the trade [e.g., Herwin 1976], the same strong market forces just mentioned, coupled with marked demographic changes in the workforce (particularly a large and growing influx of foreign-born workers), have significantly reduced the number of such longer-term workers to a degree that cannot be estimated [Shanahan 2008]. Consequently, the subgroup of roofers specializing in hot asphalt work not only has declined substantially in size; the typical tenure of these workers in the trade is dwindling as well.

The worker population figures for Europe are believed to be roughly in the same order of magnitude as the U.S. Rühl [2007] estimates that there are 13,000 roofing contractors in Germany alone, most of them with fewer than 10 employees. Because the use of hot asphalt in Europe has largely disappeared, the prevalence of the fume exposures that can occur on these jobs is well below U.S. levels.

2. Chemistry and Physical Properties of Bitumens Used in Roofing

Because bitumen is used in a number of roofing products and systems calling for different physical properties, both straight run bitumens, and oxidized bitumens processed to a range of viscosities, are used in roofing. Historically, both straight run and oxidized bitumens have been manufactured by petroleum refineries, and this remains largely true in Europe today. A separate description of the global bitumen manufacturing industry describes North American and European bitumen manufacturing processes, and the chemistry and physical properties of straight run and oxidized bitumens, from the refiner's perspective [AI 2011]. In North America, most oxidized bitumen is produced downstream of refineries, by roofing product manufacturers and other bitumen processors who acquire straight-run bitumen from refineries for use as feedstocks for oxidation operations. The following discussion, together with that in Section 3.1.1, supplements the manufacturers' information with additional data on bitumen oxidation based on North American experience and practices.

2.1 Chemistry of Air Blowing

Oxidation, or air blowing, is the process of passing air through heated bitumen to raise the softening point/viscosity of the bitumen while maintaining much of its flexibility at

lower temperatures. The use of this process dates from the late 19th century [Byerly 1894] and it is used to make a wide variety of products with markedly different softening points depending on the extent of oxidation used. On one end of this continuum are very slightly oxidized bitumens used for felt saturant and modified bitumen membranes, which are oxidized to softening points below 50°C, in the range of air rectified bitumens. The hardest bitumens typically used in roofing products – BUR products meeting North American specifications for Types III and IV, and shingle coatings – are oxidized to softening points of roughly 100°C. These products, however, actually lie at an intermediate point on the continuum of bitumen oxidation. At the upper end of the range are tire processing aids and drilling mud additives oxidized to softening points around 150°C. It is difficult to achieve softening points higher than this with commercial oxidation equipment operated at standard temperatures.

2.1.1 Broad Chemical Analyses: The chemistry of bitumen and the chemical changes taking place during air blowing are very complex and not fully characterized. This is not surprising considering the nature of bitumen – namely, everything remaining after the distillation of crude oil, which itself is the product of decomposition of biological material over geological periods of time.

At the temperatures of the air blowing process (204 to 277 °C [400 to 530 °F]) [Boduszynski 1981; Corbett 1979], the oxidation reactions ultimately yield compounds of higher apparent molecular weight through increased polarity and dehydrogenation [Boduszynski 1981; Corbett 1975; Moshopedis 1975; Goppel 1955].

The molecular weight that is determined for the material is highly dependent on the measurement technique. Bitumen has many polar molecules that bond together to form what look like large molecules, but are in reality large groupings of smaller molecules held together by intermolecular forces [Boduszynski 1981]. While many techniques, including the data presented below, show increased apparent molecular weight with air blowing they do not necessarily separate these groupings of smaller molecules. Boduszynski used Field Ionization Mass Spectrometry to achieve this separation and he showed that true molecular weight did not increase with oxidation.

Bitumen is commonly characterized by separation into components based on solubility and adsorption characteristics. [Corbett 1969]. Asphaltenes are defined as those components of bitumen insoluble in heptane, with the soluble fraction commonly referred to as maltenes. The maltene fraction can be further separated by elution through chromatographic columns using progressively more polar

solvents. Materials that pass through the column with low-polarity solvents are saturated hydrocarbons (paraffins and cycloparaffins or naphthenes), and are called saturates. Use of more polar solvents first elutes naphthene aromatics (yellow to red oily liquids), and then polar aromatics (dark polar solids).

Compared with the starting bitumen flux, air-blown bitumen contains an increased proportion of asphaltenes, decreased proportions of naphthene and polar aromatics, and the same proportion of saturates [Boduszynski 1981; Corbett 1975; Moshopedis 1973]. The smaller aromatic fraction of oxidized bitumen is also more polar than the input bitumen flux [Boduszynski 1981].

The importance and form of the oxygen functionality added to bitumen in the air blowing process has been widely debated. Goppel and Knoterus [1955] emphasized ester formation and resultant linkage of molecules, while more recent studies have disputed that and emphasized the formation of carbonyls in the form of ketones, aldehydes and acids [Campbell 1966; Smith 1966; Barbour 1974]. The majority of oxygen reacted in the process is not incorporated into the bitumen but shows up as water in the gaseous effluent as a result of dehydrogenation reactions [Corbett 1975; Goppel 1955]. Also, during the air blowing process, small amounts of relatively volatile components of the bitumen are removed [Corbett 1975; Goppel 1955].

These chemical changes can be illustrated in data taken at Owens Corning/Trumbull in 1995 and presented in Table 4. Extensive chemical analysis was done on both the oxidizer input bitumen (flux), and the shingle coating bitumen made by air blowing that flux. This was done for pairs of input and output from 16 different manufacturing facilities. In all cases the material was blown to shingle coating – a product at the intermediate extent of oxidation characterized by about a 100°C softening point. Tests included elemental analysis, separation by Iatroscan (a type of thin-layer chromatography), apparent molecular weight by Gel Permeation Chromatography, and infrared analysis. This set of data represents a myriad of crude sources and many supplying refineries. The average value for all the input

Table 4
Average Properties of Roofers Flux and Shingle Coatings in Sixteen Owens Corning Plants

Property	Bitumen Inputs (Averages)	Bitumen Coatings (Averages)
Softening Point (°F)	Not measured	211
Penetration @ 77°F (dmm)	Not measured	17
Carbon (%)	85.5	85.3
Hydrogen (%)	10.9	10.5
Oxygen (%)	0.58	0.98
Nitrogen (%)	0.48	0.49
Sulfur (%)	2.55	2.92
Saturates (%)	15.1	15.5
Naphthene Aromatics (%)	34.2	24.0
Polar Aromatics (%)	39.8	40.5
Asphaltenes (%)	10.9	20.0
Number Average MW by GPC	309	442
Weight Average MW by GPC	1716	7715
IR Peak Assignment (IR Peak Wave Nos.)		
Aliphatic carbonyl (1700cm ⁻¹)	0.08	1.74
Aromatic quinines (1600cm ⁻¹)	3.97	5.16
Methylene CH ₂ , methyl CH ₃ (1465 cm ⁻¹)	24.97	23.68
Methyl (1370cm ⁻¹)	5.41	5.34
Aromatic amine (1300cm ⁻¹)	0.26	0.27
Aromatic carbon oxygen (1250 to 1098 cm ⁻¹)	0.39	0.58
Sulfoxide (1030 cm ⁻¹)	0.20	0.21
Alkylated aromatic (870 cm ⁻¹)	1.46	1.45
Total absorption (1810 to 920 cm ⁻¹)	83.35	104.17
Total carbonyl (1810 to 1530 cm ⁻¹)	5.09	11.23

Source: Owens Corning

bitumen (or fluxes) is compared with the average value for all the bitumen coatings in Table 3. It can be seen that the largest chemical changes driving the change in softening point and penetration were the 70% increase in oxygen content, the 30% decrease in naphthene aromatics, the doubling of asphaltene content, the large increases in apparent molecular weight, and the large carbonyl increases. Both C13 and Hydrogen Nuclear Magnetic Resonance on a number of these bitumens confirmed the lack of large molecular changes to the air-blown bitumens, supporting the notion that the apparent changes in molecular size are due to inter-molecular bonding.

2.1.2 Polynuclear Aromatic Compounds: Because of inefficiencies in the distillation processes used to make bitumen from crude oils, bitumen contains trace levels of unsubstituted polynuclear aromatic hydrocarbons (PAHs) as well as the broader class of 4- to 6-ring polynuclear

aromatic compounds (PACs), which includes alkylated and non-alkylated PAHs as well as heterocyclic compounds containing nitrogen, oxygen, and sulfur [Kriech 1999; Wess 2004; AI 2011]. The effect of oxidation on the concentrations of polynuclear aromatic compounds in bitumen and bitumen fumes has not been rigorously studied. A few studies have reported PAC concentrations in individual straight run and oxidized asphalts [e.g., Brandt 1985, 1999; Preiss 2006; Kriech 2007]. However, because of the wide compositional variability among crude oils and bitumens, any differences in the PAC concentrations found in these studies may be attributable to these factors rather than the impact of oxidation.

In general, it is not likely that oxidation increases the concentration of PACs because oxidation temperatures (240-270°C) are too low to cause significant PAC formation, which requires pyrolysis and typically takes place at temperatures above 500°C [AI 2011; Wess 2004]. In fact, some support for the proposition that oxidation could reduce the active PACs in bitumen can be found in scientific studies comparing straight run and oxidized bitumens.

Several studies are available comparing materials made from the same crude source and bitumen processing. Holleran et al. [1995] found that air blowing significantly reduced the mutagenic potency, determined using the Modified Ames assay, of several refinery streams including a solvent deasphalted residuum blended with oil which is compositionally similar to bitumen. Holleran did not measure MIs on fumes generated from these materials. Blackburn [1990] used the Modified Ames assay to test the mutagenicity of laboratory fumes generated from two samples based on the same bitumen: (i) a type 3 BURA made by oxidizing a blend of solvent treated bitumen with a hydrotreated oil, and (ii) an AC20 paving grade made by simply blending the same solvent treated bitumen with the same hydrotreated oil. The hydrotreated oil and its fumes were shown to be non-mutagenic. The MIs for the BURA fumes samples (6.3 and 3.7 generated at 450 and 600°F (232 and 316°C), respectively) were lower than the MI of the straight run starting bitumen (8.0 at 450°F / 316°C), although the authors noted that the results were very similar when both MI and quantity of fumes were considered. Another study by Eurobitume [2006] compared fumes from a lightly oxidized (air rectified) bitumen to fumes from a straight run bitumen from the same crude source and refinery. Both bitumen samples were prepared to have similar properties, one was lightly oxidized and the other was distilled more extensively. There were no significant differences in PAC content as determined by a fluorescence assay that has been correlated to PAC content of bitumen fumes [Osborn 2001], nor were there significant differences in simulated distillation values, or in the sum of nine detectable

PAHs measured on the fumes.

Although these data strongly suggest that oxidation does not increase the PAC content of bitumen or bitumen fumes, each of the available studies has limitations. The Holleran [1995] and Blackburn [1990] studies did not evaluate commercially representative bitumens. The samples tested by Eurobitume [2006], although made from the same crude source, were processed separately, precluding a direct comparison of an oxidized bitumen to its straight run feedstock. And none of the studies evaluated the broad range of oxidation levels used in the bitumen industry today. For these reasons, the U.S. bitumen roofing industry is conducting a rigorous study designed to address these limitations. The results are expected to be available in the first half of 2011.

2.2 Physical Properties of Bitumens Used in Roofing

The physical properties of some bitumens used in roofing have been summarized in several studies [Puzinauskas 1982; Greenfeld 1960; Wilkinson 1958; Puzinauskas 1979]. All these focused on properties of oxidized bitumens, while the 1979 Puzinauskas study also established that two common measurements of bitumen volatility – the Loss on Heating and Flashpoint tests – correlated to gaseous, vapor, and mist or aerosol components of the bitumen fume generated in a roofing kettle. Unfortunately, these studies were limited to bitumens oxidized to softening points typical of BUR and shingle coatings and therefore do not characterize the spectrum of bitumens used in roofing as described above. In a separate study, Puzinauskas [1978] subjected a Type III BUR bitumen and a common AC-10 paving bitumen cement to a series of standard tests for physical properties. The results show that the two materials exhibit wide differences in viscosity, softening point, penetration, flash point and loss on heating, all suggesting that the oxidized Type III BUR bitumen is far less prone to produce fumes at any given temperature. However, Puzinauskas [1978] did not test straight-run and less extensively oxidized bitumens used in the roofing industry. In addition, because the oxidized bitumen tested was not manufactured from the specific straight-run material studied by Puzinauskas [1978], the results do not directly measure the change in properties that occurs as a straight-run bitumen is oxidized into a high-softening-point roofing bitumen.

To address these data gaps, an Owens Corning study [Trumbore 2008] (Appendix D) applied a series of standard ASTM tests to bitumens made from commercially common crude sources and processed to typical performance specifications for the most important straight run and

oxidized bitumen products in the U.S. roofing market. The results, displayed in Tables 5 and 6, show that bitumens used in roofing, even if they are made from the same or similar crude sources, exhibit a very broad range of softening points, penetrations and viscosities, as well as markedly different fume emissions potential. The results also identify the extent of oxidation as an important factor in explaining the significant variability in the physical properties and volatility of bitumens. In each crude source comparison group, each incremental change in the extent of oxidation produced marked changes in softening point, penetration and viscosity. In addition, measures of volatility and fuming potential decreased markedly as the straight run roofer's fluxes were subjected to increasingly greater oxidation processing.

These results are consistent with those of other studies, including Puzinauskas [1978] and an EPA [Kariher 1991] kettle emissions study which found negligible emissions from an oxidized Type III BUR bitumen at 163°C, a temperature that is associated with substantial fume emissions from straight-run bitumens (e.g., Puzinauskas [1975]). The Trumbore [2008] data confirm the common observation that, in order to reduce viscosities to levels suitable for manufacturing, processing and application operations, some higher-softening-point roofing bitumens, such as oxidized BUR materials, must be heated to substantially higher temperatures than other (e.g., straight-run or less extensively oxidized) roofing bitumens, such as roofers flux and polymer modified bitumen.

The upshot is that it is erroneous to assume, as some existing reviews do, that all bitumens used in roofing are oxidized (e.g., IARC [1985]), or have physical properties and fuming characteristics similar to BUR bitumens (e.g., NIOSH [2000]). The recognition that bitumens used in roofing exhibit a wide range of physical properties and respond to heating in markedly different ways has two important implications that are examined in Section 4 of this paper. First, the only meaningful way to classify bitumen roofing products according to their fume exposure potential is to group them according to application method – i.e., “hot”, “soft” and “cold”. Second, although temperature is certainly a significant factor in fume emission rate and composition [Thayer 1981; Brandt 1985; Machado 1993; McCarthy 1999; Brandt 1999; Knecht 1999; Reinke 1993,

2000; Franzen 2000], it is inappropriate to rely on temperature alone as an indicator of fume exposure potential in hot-application operations. Other considerations, including the physical properties of the bitumen and operational factors such as work practices and environmental conditions, must be considered in conjunction with temperature in evaluating potential worker fume exposures.

2.3 Product and Performance Specifications for Bitumen Roofing Products

Industry-wide specifications exist for many bitumen roofing

Table 5:
Physical Properties of Four Bitumens Typically Used in North American Roofing Made from a Commonly Used Venezuelan Crude Source

Tests and Units	ASTM Test Method	Straight-Run Bitumens		Oxidized Bitumens	
		Polymer Modified Bitumen Base	Roofer's Flux	Shingle Saturant*	Shingle Coating*
Softening Point (°C)	D36	41	41	54	101
Penetration at 25°C (dmm)	D5	163	219	64	18
Viscosity at 149°C (cps)	D4402	145	143	355	13,000
Loss on Heating at 163°C (%)	D6	0.190	0.098	0.028	0.016
RTFOT at 163°C (%)	D2872	0.1880	0.0418	-0.0554 [†]	0.0043
Flashpoint (Open Cup) (°C)	D92	313	313	324	316

Source: Trumbore [2008] (see Appendix D).

* The Shingle Saturant and Shingle Coating Bitumens were blown from the Roofer's Flux tested in this study.

† Negative numbers indicate a weight gain that can occur in the RTFOT test for samples with low levels of volatiles. As described in ASTM D2872, oxygen reactions can result in a weight gain that exceeds the weight reduction arising from the loss of volatiles during the test.

Table 6:
Physical Properties of Four Bitumens Typically Used in North American Roofing Made from a Commonly Used Saudi Crude Source

Tests and Units	ASTM Test Method	Straight-Run Bitumens		Oxidized Bitumens	
		Polymer Modified Bitumen Base	Roofer's Flux	Shingle Saturant*	Type III BUR Bitumen*
Softening Point (°C)	D36	42	37	54	85
Penetration at 25°C (dmm)	D5	162	310	53	17
Viscosity at 149°C (cps)	D4402	150	95	313	2,135
Loss on Heating at 163°C (%)	D6	0.084	0.165	0.009	0.010
RTFOT at 163°C (%)	D2872	0.0660	0.2991	-0.0730 [†]	-0.0208 [†]
Flashpoint (Open Cup) (°C)	D92	318	318	335	332

Source: Trumbore [2008] (see Appendix D).

* The Shingle Saturant and Type III BUR Bitumen were blown from the Roofer's Flux tested in this study.

† Negative numbers indicate a weight gain that can occur in the RTFOT test for samples with low levels of volatiles. As described in ASTM D2872, oxygen reactions can result in a weight gain that exceeds the weight reduction arising from the loss of volatiles during the test.

products and roof waterproofing systems. A partial list of widely recognized European and North American product standards published by the European Committee for Standardization (CEN), ASTM International (ASTM), and the Canadian Standards Association (CSA) appears in Appendix C. In general, these standards are based on physical and performance tests commonly specified to describe the properties that make bitumen products suitable for specific end uses. The tests commonly used include softening point, penetration, viscosity, volatility (measured as weight loss) and flashpoint. See the Glossary for more details on these tests, including references to widely-accepted standard test methods.

In addition to industry-wide specifications such as those published by CEN, ASTM and CSA, individual manufacturers often have proprietary specifications for bitumen components they purchase in order to manufacture different bitumen roofing products. Common examples are:

1. Bitumen coatings used to produce roofing shingles and roofing membranes often have narrower needle penetration and softening point specifications than are found in the standard specifications. In addition, manufacturers typically specify melt viscosity, durability in accelerated aging tests, stain index, and flashpoint to ensure quality of the product and safety in their operations.
2. The bitumen base used to make polymer modified membranes is often specified by penetration, similar to the penetration-based grading of paving bitumens in Europe.

3. Exposures and Emissions during Manufacture of Bitumen Roofing Products

3.1 Production Methods

In large part due to the mechanized character of manufacturing operations and the use of closed systems, exposures to bitumen fumes in manufacturing operations are generally well-controlled. Detailed descriptions of the manufacturing processes for bitumen roofing products have been published by NIOSH [2001]. Despite the variety of bitumen roofing products made today, there are substantial similarities in the processes used to make these products. Accordingly, for the sake of simplicity this paper describes four manufacturing processes which encompass the spectrum of the bitumen roofing industry. The first section below addresses air blown bitumen, which is included because, in North America,

the roofing industry manufactures this material. The next two sections describe the manufacture of the two largest-volume bitumen roofing system components, fiberglass-based shingles and polymer modified bitumen membranes. The fourth section addresses liquid bitumen products manufacturing.

3.1.1 Air Blowing of Bitumen

3.1.1.1 Raw Materials for Production of Oxidized Bitumen: Bitumen feed stocks vary with crude oil source as well as with refinery processing. The crude slates are described as heavy (high-asphalt content) to light, as well as sweet (low sulfur) to sour. Air-blown bitumens can be produced from many bitumen input materials and in the US these are typically referred to as “flux” or “roofer’s flux”. These fluxes tend to be the residuum from the vacuum distillation of sweet light crudes which produce less viscous bitumens (compared to paving grades) that are known through experimentation and experience to produce the desired end products with appropriate processing times and conditions in an air-blowing tower. There is, however, no clear demarcation between roofer’s fluxes and bitumens used in paving. In some cases roofing fluxes can correspond to softer grades of paving-grade bitumens, such as AC-5 or 150/200 pen paving grades, or even commodity paving products such as PG64-22. Blends of low viscosity bitumen with paving grades or even solvent de-asphalted residua are also used as fluxes to make oxidized roofing bitumen. In the US most oxidized bitumen is produced solely from bitumen inputs. However, high flash-point oils – such as bright stock or reclaimed motor oil – can be used as a blend stock to make roofing and industrial products [AI 2011]. For example, the oxidized bitumen used to coat steel culvert pipes is typically made by oxidizing a blend of bright stock and bitumen. Although a myriad of different bitumen materials can be used as feedstocks for oxidation, they share the requirement of being high flash materials for safe operation of the process. Because the air blowing process is carried out at temperatures near 260°C (500°F), the preferred flash point is in excess of 288°C (550°F).

As discussed elsewhere [AI 2011], it is the responsibility of bitumen manufacturers to identify any human health or environmental hazards associated with the use of any non-bitumen blending stocks and disclose them to downstream processors and consumers in safety data sheets and other forms of hazard communication.

3.1.1.2 Production Practices for Air-Blown Bitumens: In Europe, most oxidized bitumen is manufactured by petroleum refineries, and refinery bitumen manufacturing processes are described elsewhere [AI 2011].

In contrast, in North America most oxidized bitumen is produced downstream of refineries, by roofing product manufacturers and other bitumen processors which acquire straight-run bitumen, called roofer's flux, from refineries for use as feedstocks for oxidation operations. The following description is based on the North American practice.

In simple terms, air-blown bitumen is produced by injecting air into hot bitumen and controlling the exothermic reaction that takes place. Early references to air blowing [Abraham 1945] of bitumen cite use of horizontal tanks, with air spargers and virtually no pollution control. Modern air blowing is carried out in vertical towers or reactors with water jackets to allow precise temperature control, and with extensive pollution controls on the fume stream – typically, thermal oxidizers with the waste heat recovered as steam or used to heat bitumen. The tower reactors are commonly called stills, oxidizers, or converters in the industry. Temperature, airflow, and time of reaction are all carefully controlled. Modern towers are typically 2.4 to 3.7 meters (8 to 12 feet) in diameter and 9.1 to 18.3 meters (30 to 60 feet) tall, with spargers and no other internal parts. Capacity generally ranges from 45 to 150 m³ (12,000 to 40,000 gallons) and the process is generally performed in a batch mode, although continuous operations exist. The process is also typically run at close to atmospheric pressure.

Bitumen is typically blown at temperatures ranging from 204°C to 277°C (400 to 530°F). The upper limit on reaction temperature is chosen to allow for control of the reaction rate using cooling water, control of the amount of oil byproducts, and to maintain a safe difference between processing temperature and either bitumen flashpoint or the auto-ignition temperature of the oil byproducts. Air flow, injected through spargers from blowers, is typically in the range of 0.4 to 1.4 m³/min/ton of bitumen (15 to 50 standard cubic feet per minute/ton), while superficial gas velocity in the towers is generally in the range of 0.06 to 0.15 m/s (0.2 to 0.5 ft/s). This level of airflow puts the gas/liquid flow in the tower in the churn-turbulent region [Shah 1982] and provides extensive mixing capability in the tower, essentially creating a continuous stirred-tank reactor by virtue of the gas flow alone. Various enhancements to the typical process described above (agitation for bubble dispersion, periodic coalescence and re-dispersion of the air, and reacting under pressure) have been proposed [Rescorla 1956; Senolt 1969, 1975, 1976] but, at least in North America, have not been widely adopted.

Typically during the air blowing reaction, the softening point of the bitumen increases linearly with time, viscosity increases exponentially, and penetration decreases asymptotically. Oxygen is consumed by the reactions taking place in the air-blowing process, resulting in fumes with typically less than

10% oxygen exiting the tower at peak reaction temperatures and reaction rates. An air blowing reaction run at constant temperature will have higher rates of reaction early in the reaction with these rates decreasing as the reaction proceeds. These fumes also contain evaporated light hydrocarbons as well as reaction products that include steam and hydrogen sulfide.

In addition to water jackets for cooling, direct injection of water has also been used to control the reaction temperature. This is very effective, but has the drawbacks of adding large quantities of steam to the fume load on the incinerator, and raises the issue of a process upset caused by too much water being injected without adequate mixing and evaporation.

Production times and temperatures are determined by monitoring the physical properties of the bitumen, typically softening point and penetration. When desired product physical properties are achieved, the airflow to the still is stopped. The product is then pumped to a storage tank.

There has been a great deal of work on the use of catalysts to affect both processing times and product properties. Of the hundreds of materials explored over the years as catalysts [Abraham 1945], only two – ferric (or ferrous) chloride and phosphoric acid (or phosphorus pentoxide) – remain in common use today. Ferric chloride speeds the rate of reaction and produces a higher pen (softer) bitumen at equal softening points, while phosphoric acid only impacts the physical properties.

3.1.2 Bitumen Shingle Manufacturing: Bitumen roofing shingles made from fiberglass mat are typically manufactured in a process shown schematically in Figure 10. A thin fiberglass mat is impregnated and coated with a filled bitumen mixture, colored mineral granules are added to the top surface, a parting agent is added to the bottom surface, appropriate bitumen based adhesives are applied, and then the shingle is cut to size and packaged. The primary source of bitumen fumes is the coating area. Fumes are also generated in the area where adhesives are applied, but at far lower levels because of smaller surface area and because the smaller mass of adhesive cools rapidly. Fumes from the coater and adhesive applicator (Europe) are typically collected by local exhaust ventilation. Various fume emission controls are available for reducing fume releases to the outside air, including mist eliminators, high-velocity air filters or fiber bed filters, electrostatic precipitators, incinerators and regenerative thermal oxidizers. Data on plant emissions to the outside air are discussed in Section 3.3.

The bitumen/filler mix is typically two parts by weight of a finely divided limestone filler mixed with one part by

weight of an oxidized coating bitumen. The filled bitumen is typically applied to the fiberglass mat in the coating pan at a temperature of from 170 to 230°C (338-446°F). Prior to mixing with the filler the bitumen may be heated above this temperature range to achieve the desired filled bitumen temperature. In that case, however, the bitumen is completely enclosed inside the process equipment. Thus, fume exposure potential really begins at the coating pan.

Two types of bitumen-based adhesives are used in bitumen shingle manufacturing. One is used to laminate multiple shingle layers together to make a thicker product, and the other is applied to the shingle for activation in the field by ambient temperature and sunlight to adhere each shingle to the shingle below it once installed on the roof. The adhesives are applied to the sheet with a wheel or by extrusion, typically at a temperature of 160 to 190°C (320-374°F). Both adhesives are commonly made from straight-run bitumen mixed with SBS elastomers; in some plants oxidized bitumen is used.

Finally, cutting operations vary depending on whether single layer or laminated shingles are being produced. All cutting is done at ambient temperature with no bitumen fume exposure.

3.1.3 Modified Bitumen Membrane Manufacturing:

Polymer modified bitumen membranes are made in a process shown schematically in Figure 11. A straight-run or lightly oxidized bitumen is mixed with either atactic/isotactic polypropylenes (to make APP modified bitumen) or styrene-butadiene-styrene block copolymer (to make SBS modified bitumen) and finely divided limestone. Other fillers may be used, and some manufacturers substitute fire retardants for fillers to achieve fire ratings. The mixture is heated to approximately 200°C (392°F). The filled bitumen is then applied to a nonwoven mat made of glass and/or polyester fiber. Rollers are used to meter thickness. The membrane is cooled by cooling drum or water bath while either a plastic film (e.g. PP, PE, PET) or minerals are used as finishing to the top and bottom surface

Figure 10 Fiberglass Shingle Production Line

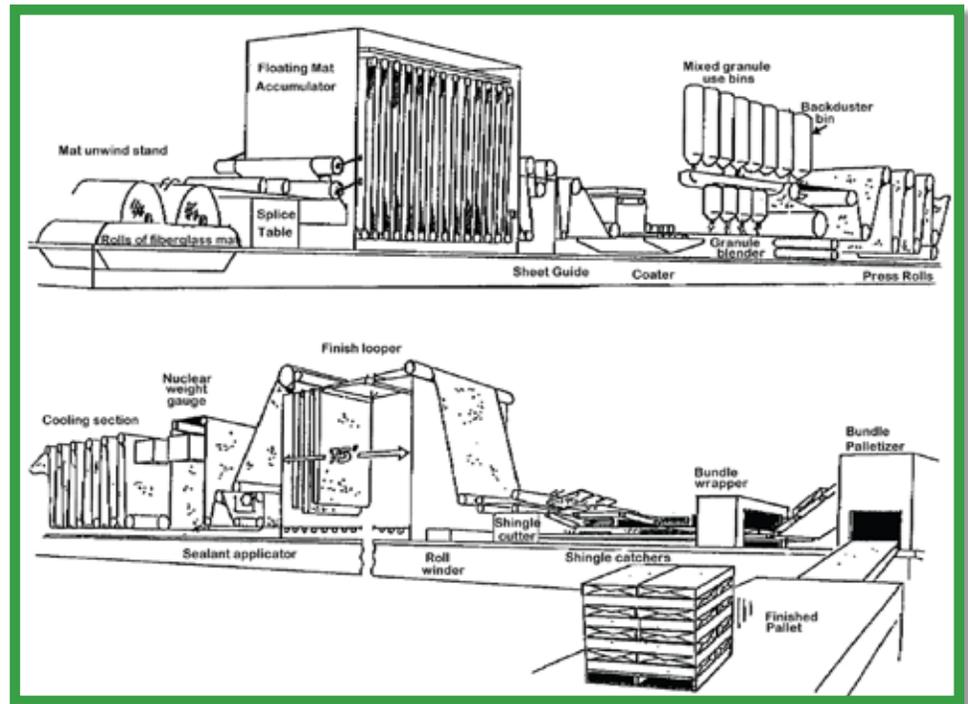
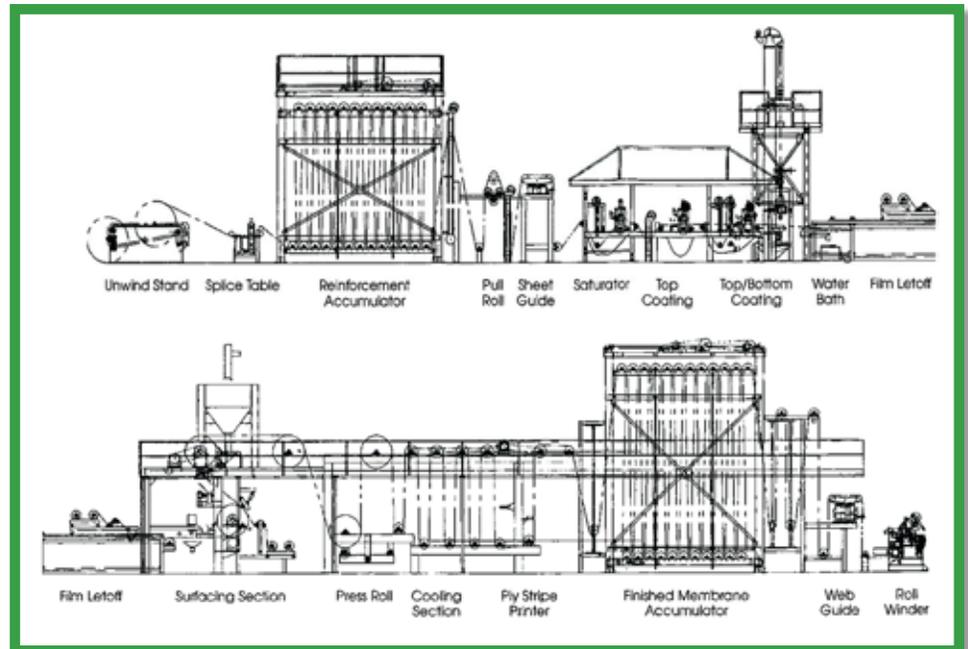


Figure 11 Polymer Modified Bitumen Production Line



of the membrane. The product is cooled completely and is wound in rolls for packaging. Bitumen fumes and dust from the individual operations in the process are collected in hoods and removed from the work area. Available emission controls are the same as the capture devices for coaters, discussed above (see Section 3.1.2).

3.1.4 Liquid Bitumen Products Manufacturing:

Liquid bitumen products are typically manufactured in a process similar to that of common adhesives. The bitumen resin binder, either a cutback or an emulsion, is combined with finely divided fillers and sometimes polymers or aluminum paste and other additives in large, low shear, batch mixing vessels and blended until homogenous. The manufacturing process typically takes place under ambient pressure and at temperatures that range between 32.2 to 65.5°C (90-150°F). Under these operating conditions, there is no reason to expect volatilization of the bitumen constituents. Instead, potential worker inhalation exposure is associated with solvent vapors and airborne dusts from the fillers.

The manufacture of the bitumen resin binder used in the preparation of liquid bitumen products involves the use of bitumen at elevated temperatures in a closed pipe system. The process involves co-blending the bitumen, which is at a temperature between 149 to 177°F (300-350°F) with the carrier liquid, either a hydrocarbon solvent or water.

In the case of bitumen cutback, the heated liquid bitumen is meter-pumped through a piping system to a storage tank and the ambient temperature solvent is either meter pumped in-line through a static blender in conjunction with the bitumen or pre-introduced to the storage tank prior to the addition of the bitumen. The composite blend in the storage tank is then re-circulated and/or mixed until homogenous.

Similar to bitumen cutback, bitumen emulsions are prepared in closed pipe systems. The water carrier, often referred to as a soap solution because of the included emulsifying surfactants, is generally warmed to a temperature between 32.2 to 50°C (90-122°F) prior to blending with the liquid bitumen. Typical bitumen emulsion manufacture involves meter pumping the two liquids through a high shear, colloid mill, where the bitumen is sheared into micron size droplets and homogeneously suspended throughout the soap. At the discharge of the colloid mill, the bitumen emulsion is pumped to a storage tank for packaging or for use in the preparation of other liquid bitumen products.

Because of the closed design of the bitumen cutback and emulsion blending operations significant worker exposure to bitumen fumes is not anticipated during routine operations.

3.2 Exposure Data

3.2.1 Sampling and Analytical Methods: Employees working with bitumen heated above its softening point are potentially subjected to aerosol and vapor emissions consisting mainly of aliphatic hydrocarbons, cyclic alkanes, and low levels of polycyclic aromatic compounds

[Wess 2004]. As developed above, these emissions can vary in composition and concentration depending on crude source, bitumen manufacturing processes, physical properties affecting temperature susceptibility and volatility, application temperature, work practices, and weather and other environmental factors.

Identification of all of the individual compounds present in bitumen fumes is not practical for routine exposure monitoring. For this reason, industrial hygienists have employed broad or summary measures that are not specific to bitumen fumes. Accordingly, it is always necessary to consider potential confounding by non-bitumen materials in both inhalation and dermal measurements of exposure to bitumen fumes. The ratio of the vapor and aerosol fractions of the fumes varies widely depending on type of bitumen, processing temperature, work practices and other factors (e.g., Kriech [2004]). One recent study found that, for rolled asphalt, the fumes consisted of more than 90% vapor, while for mastic asphalt at 250°C, the fumes were nearly 90% aerosol [Rühl 2006].

In North America, only the aerosol fraction of bitumen fume exposures are typically measured, usually as total particulate (TP) and the soluble fraction (SF) of total particulate, which represents the organic fraction of the particulate exposure. Most existing organic particulate data are benzene soluble fraction (BSF). The data are based on NIOSH method 5023 prior to 1996, and NIOSH 5042 after 1996, or comparable methods. Both TP and SF are gravimetric measurements with the latter being a measure of the aerosol portion of the bitumen fume [AI 2011]. As reported by Calzavara [2003], total particulate samples in bitumen roofing manufacturing facilities often collect significant amounts of inorganic particulates which are unrelated to bitumen fumes. Volatile organics, where reported, are a measure of the vapor fraction of bitumen fume [AI 2011] and are determined using a variety of methods including collection tubes using XAD and charcoal sorbents. A measure of the total organic fraction of the fume exposure (both the aerosol and vapor fractions) can be taken by adding an XAD tube after the NIOSH samplers followed by GC/FID analysis as described by Heritage [Kriech 2004, 2010]. This combination (referred to here as the NIOSH/Heritage method) collects both the aggregate volatiles and the semi-volatile compounds in bitumen fumes, often referred to as Total Organic Matter (TOM), and has been used in many industrial hygiene studies of bitumen fumes.

In Europe, the available data on bitumen fume exposures are based on IFA Method 6305 [IFA 1997]. The IFA method is described in more detail in Ekstrom [2001] and Kriech [2010]. In the IFA protocol, aerosol is collected on a glass fiber filter

and vapor on an XAD tube, and both are analyzed using infrared spectroscopy. The sum of the two fractions is usually reported; the aerosol fraction is also reported separately in some instances.

In a laboratory study, Ekstrom [2001] found that IFA Method 6305 showed little correlation to U.S. methods, with the German method generally resulting in lower values for aerosols and higher values for TOM. However, a subsequent field study [Kriech 2010] compared the NIOSH/Heritage method to IFA Method 6305-2 [Breuer 2008], which modified the German method to address factors that were thought to explain the lack of correlation. Kriech [2010] found much better correlations (R2s ranging from 0.78 to 0.91) and derived a series of conversion factors between the two methods. The authors emphasized, however, that conversion factors are useful only for large data sets and are not applicable to individual measurements. The data for the roofing sites (production and torch- or blower-application of Modified Bitumen membranes) showed generally that the German method tends to produce higher results.

All determinations of worker exposures presented below, and in Section 4 for application operations, are personal samples of the breathing zones of the workers studied. Although some exposure surveys include area samples taken at one or more fixed locations in the work area under study, such area samples are generally not considered accurate measures of the exposures of individual workers.

3.2.2 Worker Inhalation Exposures:

Using methods like NIOSH Method 5042 that evaluate the aerosol fraction of bitumen fume exposure, more than 2000 measurements have been reported of worker bitumen fume exposures in North American roofing manufacturing operations [Apol 1977, 1978; Axten 2011 (manuscript in preparation); Calzavara 2003; Fayerweather 2011 (manuscript in preparation); Gamble 1999; Hicks 1995, Okawa 1977, 1978a,b]. These data indicate that bitumen fume inhalation exposures have declined significantly since the 1980s in bitumen roofing production plants to levels that are typically well below health based limits (e.g., ACGIH [2001], NIOSH [1977], Cal/OSHA [2003]) for bitumen

blending and oxidation operations, and for fiberglass shingle manufacture. This review of North American exposure data centers on the soluble fraction of total particulate because it is the most appropriate measure of the aerosol fraction of bitumen fume exposure in roofing product manufacturing facilities [Calzavara 2003].

During the 1970s five NIOSH health hazard evaluations (HHEs) conducted in bitumen roofing manufacturing facilities reported exposures ranging from 0.21 to 6.8 mg/m³ SF [Apol 1977, 1978; Okawa 1977, 1978a, b]. Study specific geometric mean SF exposures (referring to the geometric mean of all the measurements in a study) ranged from 0.46 mg/m³ to 1.6 mg/m³. Several studies done since 1991 [Radian 1991, Gamble 1999, Calzavara 2003, Axten 2011 (manuscript in preparation)] show much lower exposure levels in fiberglass

Table 7
Summary of Recent U.S. Industrial Hygiene Surveys of Worker Exposures to Bitumen Fumes Measured as BSF and TP in Shingle Manufacturing Operations

Work Station	BSF [†]			TP [†]		
	n	GM [‡]	Max [‡]	n	GM [‡]	Max [‡]
Inorganic Shingle Manufacturing						
Radian [1991]						
Loader/Bitumen Handler	6	0.31	0.71	6	0.51	0.94
Slate Blend Operator	4	0.077	0.94	4	3.9	13
Coater Operator	8	0.2	1.6	8	1	2.5
Machine Operator	8	0.55	3.6	8	1.6	4.4
Press/Cooling Operator	7	0.32	3.7	7	2.6	11
Supervisor	1	0.32	N/A	1	1.4	N/A
Gamble [1999]						
Coater Operator	17	0.12	1.32	17	0.69	2.46
Dry End Operator	31	0.09	0.48	31	0.64	6.16
Granule Operator	4	0.21	0.46	4	2.18	2.92
Miscellaneous	4	0.03	0.03	4	0.24	0.47
Supervisor	3	0.09	0.1	3	0.52	0.68
Warehouse	16	0.04	0.17	16	0.5	2.89
Axten [2011] (Data Range: 1998 to 2005)						
Coater/Dry Felt Operator	201	0.13	3.5	120	0.84	76
Granule Applicator/Press/Surface Cooling	122	0.14	7.1	116	0.87	82
Cutter/Catcher/Laminator/Warehouse	73	0.12	2.3	43	0.73	2.5
Laborer/Utility/Relief/Maintenance	43	0.17	5.2	21	0.81	3.9
Other	23	0.10	0.34	11	0.52	6.2
Organic Shingle Manufacturing						
Axten [2011] (Data Range: 1998 to 2005)						
Various jobs	16	0.26	6.07	16	1.2	9.9

* All concentrations are 8-hour time weighted averages in mg/m³.

† Maximum measured PBZ exposure; n = total number of samples included in the summary statistics.

‡ Geometric mean PBZ concentration.

and organic shingle manufacturing (Table 7), bitumen blending and oxidation (Table 8), and polymer modified bitumen manufacturing (Table 9). Geometric mean BSF exposures in the more recent studies are generally well below 0.5 mg/m³ for all but organic shingle production. Some of the recent organic shingle data presented in Axten [2011] were collected on a line under atypical operating conditions in which the ventilation system was malfunctioning and the saturator doors were in an “open” position. These samples were valid, but not representative of normal production activities (Axten 2011). They skew the average in Table 6 for organic shingles in the 1998 to 2005 timeframe and appear as outliers in Figure 12 for 1999 production of organic shingles. Because the production of organic shingles has declined so precipitously the significance of these data for present-day operations is uncertain. One post-1990 study of U.S. manufacturing plant workers evaluated exposures to TOM [Gamble 1999]; summary results appear in Table 10.

Fayerweather [2011] reports extensive historical industrial hygiene data for Owens Corning over the last 30 years. These data show a clear decline in exposures between the 1970s and present. The historical SF exposure data from Fayerweather are shown in Table 11. Fayerweather reports an 11-fold decrease in worker exposure, measured as both TP and SF, in bitumen shingle manufacturing since 1977, and identifies the following as major factors in the decline: (1) the switch from organic to glass fiber mats, which eliminated the need for saturators, a major source of bitumen fume exposures; (2) the increased use of emission control equipment for both organic and inorganic particulates; and (3) the conversion to closed saturators in operations continuing to manufacture organic shingles. In bitumen blending and oxidising operations, Fayerweather reports a 9-fold decrease in SF, which is attributed to: (1) the increased use of pollution control equipment in bitumen truck loading operations and on bitumen storage tanks; and (2) the use of lower temperatures and placement of personnel further from pouring spouts in bitumen pouring operations.

Table 8
Summary of Recent U.S. Industrial Hygiene Surveys of Worker Exposures to Bitumen Fumes Measured as BSF and TP in Bitumen Blending and Oxidation Operations

Work Station	BSF [‡]			TP [*]		
	n	GM [‡]	Max [†]	n	GM [‡]	Max [†]
Axten [2011] (Data Range: 1998 to 2005)						
Bitumen Plant Operator	16	0.11	0.39	10	0.39	2.3
Gamble [1999]						
Stillman	2	0.05	0.1	2	0.22	0.34
Calzavara [2003]						
Asst Plant Operator	6	0.05	N/A	6	0.17	N/A
Plant Operator	2	0.08	N/A	2	0.23	N/A
Bitumen Pourer	6	0.09	N/A	6	0.4	N/A
Bitumen Truck Loading	2	0.13	N/A	2	0.46	N/A

* All concentrations are 8-hour time weighted averages in mg/m³.

† Maximum measured PBZ exposure; n = total number of samples included in the summary statistics.

‡ Geometric mean PBZ concentration.

Table 9
Personal Time-Weighted Average Bitumen Fume Exposures of Polymer Modified Bitumen Manufacturing Workers Measured as BSF and TP

Work Station	n	BSF [‡]	TP [*]
		(mg/m ³)	(mg/m ³)
Warehouse/Winder Operator	7	0.05	0.24
Dry End/Relief & Forklift	4	0.09	1
Coater Operator	25	0.12	1.54
Slate Operator	4	0.12	1.76
Cooling/Mixing Attendant	2	0.17	2.03

* Geometric mean PBZ concentration..

Source: Calzavara 2003

Table 10
Personal Time-Weighted Average Bitumen Fume Exposures of Roofing Manufacturing Workers Measured as TOM

Type of Mfg Operation	Work Station	n	GM (mg/m ³)	Max (mg/m ³)
Inorganic Shingle Mfg	Coater Operator	17	0.84	1.43
Inorganic Shingle Mfg	Dry End Operator	31	0.75	4.22
Inorganic Shingle Mfg	Granule Operator	4	0.6	0.61
Inorganic Shingle Mfg	Miscellaneous	4	0.88	3.14
Bit. Blending & Oxidation	Stillman	2	6.28	8.73
Inorganic Shingle Mfg	Supervisor	3	0.86	0.87
Inorganic Shingle Mfg	Warehouse	16	0.3	0.69

Source: Gamble 1999

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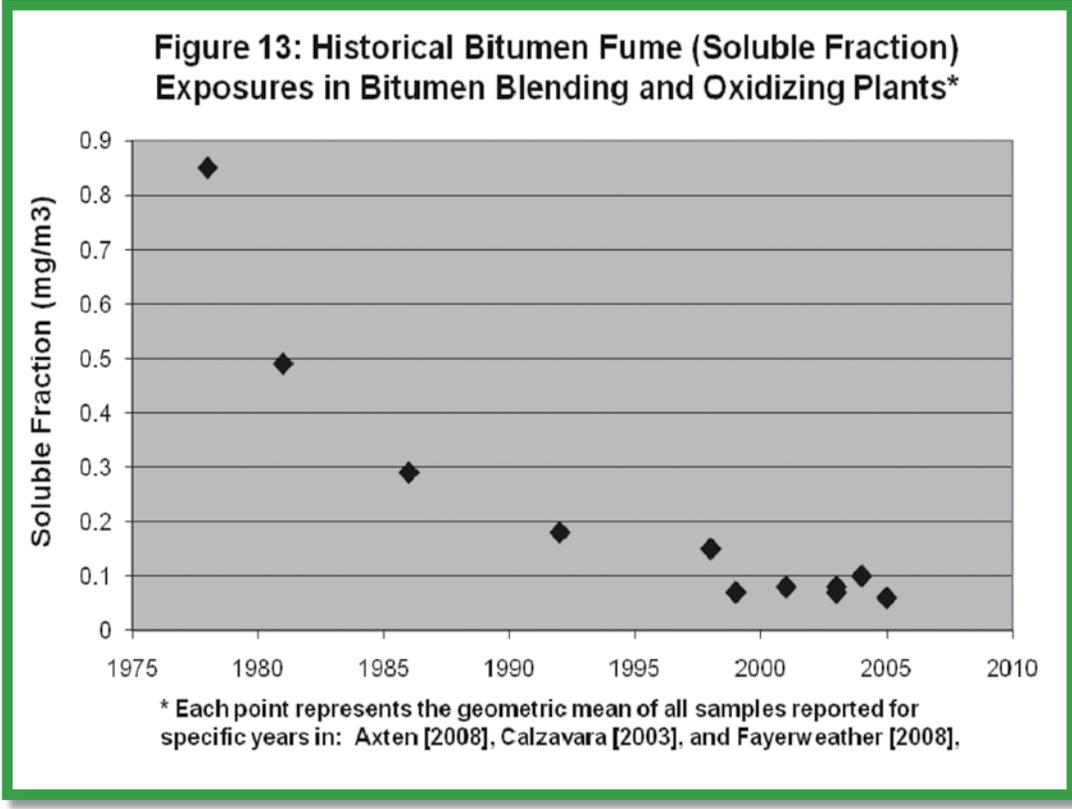
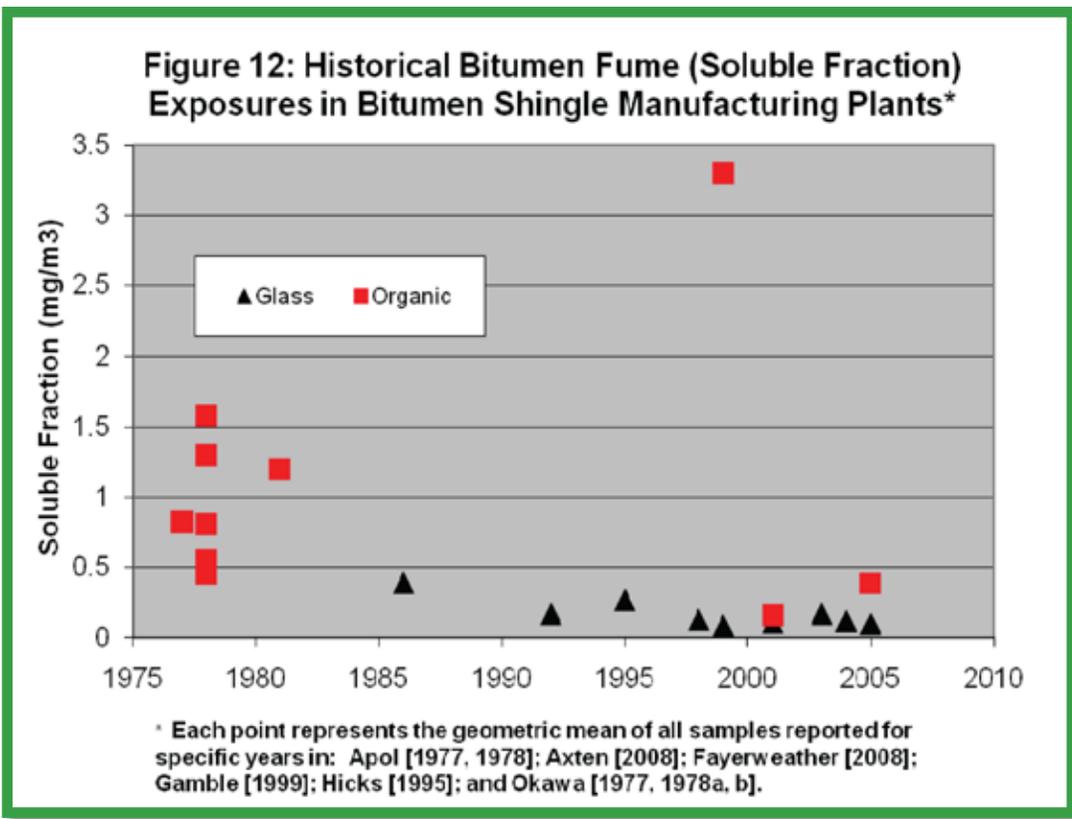
Table 11
Personal Time-Weighted Average Bitumen Fume (Soluble Fraction) Exposures
of Owens Corning Workers, 1977-2006

Process / Job Category	Time Period	N	Mean (mg/m ³)	Geom. Mean (mg/m ³)	Geom. St. dev.	Min (mg/m ³)	Max (mg/m ³)
Roofing: Saturation, Mat Tender	1977-1982	133	1.38	0.66	4.08	0.01	7.6
	1983-1988	8	0.32	0.16	4.04	0.03	0.9
	1989-1994	16	0.08	0.05	2.97	0.01	0.3
	1995-2000	5	0.06	0.04	2.60	0.01	0.1
	2001-2006	4	0.11	0.08	2.34	0.04	0.3
Roofing: Coater	1977-1982	37	0.64	0.33	3.98	0.01	2.7
	1983-1988	73	0.29	0.18	3.07	0.01	1.3
	1989-1994	94	0.19	0.11	3.14	0.01	1.5
	1995-2000	52	0.11	0.07	3.00	0.01	0.5
	2001-2006	40	0.14	0.10	2.15	0.03	0.7
Roofing: Mineralization	1977-1982	2	5.89	4.71	2.66	2.36	9.4
	1983-1988	27	0.63	0.37	3.41	0.02	2.7
	1989-1994	57	0.16	0.11	2.56	0.01	0.9
	1995-2000	31	0.14	0.07	3.35	0.01	1.0
	2001-2006	63	0.11	0.08	2.00	0.01	0.8
Roofing: Cooling & Drying	1977-1982	1	0.82	0.82	NA	0.82	0.8
	1983-1988	22	0.43	0.32	2.30	0.06	1.3
	1989-1994	50	0.17	0.10	3.12	0.01	1.0
	1995-2000	10	0.09	0.03	4.36	0.01	0.4
	2001-2006	28	0.13	0.10	2.10	0.04	0.6
Roofing: Finishing, Packaging, Warehouse & Shipping	1977-1982	1	0.44	0.44	NA	0.44	0.4
	1983-1988	7	0.31	0.24	2.60	0.06	0.5
	1989-1994	10	0.14	0.09	2.98	0.01	0.6
	1995-2000	30	0.09	0.05	3.14	0.01	0.6
	2001-2006	12	0.10	0.08	1.97	0.04	0.3
Roofing: Maintenance, Crafts, Laborer, Relief, Utility, Foreman	1977-1982			NA	NA		
	1983-1988	12	0.36	0.15	5.52	0.01	1.0
	1989-1994	5	0.29	0.28	1.20	0.21	0.3
	1995-2000	7	0.42	0.15	7.63	0.01	0.7
	2001-2006	1	0.04	0.04	NA	0.04	0.0
Bitumen: Production	1977-1982	23	0.82	0.40	3.74	0.01	6.4
	1983-1988	64	0.29	0.22	2.32	0.01	0.9
	1989-1994	167	0.18	0.10	3.21	0.01	1.4
	1995-2000	157	0.15	0.07	3.06	0.01	5.0
	2001-2006	161	0.10	0.08	1.91	0.02	0.9
Labs	1977-2006	15	0.13	0.08	2.67	0.01	0.6
Unknown	1977-2006	6	0.36	0.11	5.64	0.01	1.6
Totals		1431	0.32	0.13	3.69	0.01	9.4

Source: Fayerweather 2011. Data from unpublished manuscript supplied by the Asphalt Roofing Manufacturers Association, and are available from ARMA on request.

Figures 12 and 13 summarize all available North American data on bitumen fume exposures, measured as SF, in bitumen shingle manufacturing plants and bitumen blending and oxidising plants. Both figures plot the geometric means of the SF exposures reported for all the workers sampled in each of the available industrial hygiene surveys in specific years during the period from 1975 to 2005. Both Figures show a steady decrease in worker exposure in plants manufacturing fiberglass shingles as well as in bitumen blending and oxidising plants. The data are less clear for organic shingle manufacture.

European worker exposure data published by Rühl [2006, 2011] and Kriech [2010] for bitumen roofing product manufacturing facilities are summarized in Table 12. These data are typical for all of Europe, because only two types of production lines exist and the data are the results of industrial hygiene surveys of both types. The production of car body sound deadening systems is comparable to production of bitumen sheeting and is therefore included in table 12. As indicated above, a recent comparative field study indicates that results obtained using the revised IFA 6305-2 [Breuer 2008] are higher than those of the NIOSH/Heritage method.



Limited data are available on exposures to PAHs in bitumen roofing manufacturing operations. Hicks [1995] surveyed personal worker exposures to PAHs in six U.S. manufacturing facilities using NIOSH Method 5506; relatively few results exceeded the practical quantitation limit of the analytical method (HPLC). With few exceptions, results marginally above the PQL were obtained only for naphthalene, fluoranthene and phenanthrene, in the range of 0.2 to 8 ug/m³. Rühl (2011) presents the results of some PAH-measurements in production plants of bitumen membranes (table 13).

3.2.3 Dermal Exposures: Limited data are available on dermal exposures to condensed bitumen fumes in roofing product manufacturing plants. Dermal exposures are expected to be low because of the use of closed systems in these processes. In one North American study, dermal exposure to condensed bitumen fumes was examined using post-shift skin wipes [Hicks 1995]. Analysis for 16 unsubstituted PAHs found detectable levels of naphthalene, phenanthrene and indeno[1,2,3-cd]pyrene in trace levels (e.g., indeno[1,2,3-cd]pyrene at 25 ng/cm²).

3.3 Air Emissions Data

During 1998 and 1999 the Asphalt Roofing Manufacturers Association (ARMA), in cooperation with the US EPA, sampled multiple emissions sources at a variety of plants in the bitumen roofing products manufacturing industry to provide the database to be used for development of maximum achievable control technology (MACT) standards under the U.S. Clean Air Act. These data have been combined by ARMA with other member company data, some previously published, to develop emission factors that are representative of contemporary production practices in the bitumen roofing industry. These emission factors were published in 2005 and shared with US EPA. PAH emissions, both organic and inorganic, were judged to be minor from this industry [Trumbore 2005].

Table 12
European Data on Inhalation Exposure in Manufacturing of Bitumen Sheetting

n	Location	Exposure Metric*	Min	GM ‡	50%	95%	Max
38	Germany	V + A †	1.0	2.1	2.0	4.3	6.1
38		aerosol	0.13	0.23	0.25	0.25	0.28
49	7 countries	V + A	0.20	0.8	0.7	2.4	5.6
49		aerosol	0.06	0.14	0.13	0.4	0.6
87	8 countries	V + A	0.20	1.2	1.4	2.4	5.6
87		aerosol	0.06	0.17	0.25	0.4	0.6
Production of Car Body Sound Deadening Systems							
10	Germany	V + A	0.50	1.51	1.1	5.41	5.5
10		aerosol	all below detection limit				

* All exposures determined in accordance with IFA Method 6305 and reported in mg/m³.

† The sum of the measured aerosol and vapor fractions.

‡ Geometric mean.

Source: Rühl [2011]. Data from unpublished manuscript supplied by the Bitumen Waterproofers Association, and are available from BWA on request.

Table 13
PAH Concentrations (ng/m³) during Production of Bitumen Membrane

	A	B	C	D
1-Benzothiophene	135	45.7	26.3	45.1
Acenaphthene	65.2	<13,3	28,8	118
Acenaphthylene	<45	<5,01	<4,7	<5,43
Anthracene	39,4	10,8	4,62	8,48
Benzo[a]anthracene	<6	10,9	<1,1	<2,91
Benzo[a]pyrene	<4,41	1,03	<1,28	<1,67
Benzo(b)naphtho(2,1-d)thiophene	17,5	12,5	<0,718	<5,36
Benzo(b+j+k)fluoranthene	<9,12	<4,19	<2,15	<2,18
Benzo[g,h,i]perylene	<1,82	1,12	<0,718	<0,727
Chrysene-Triphenylene	<20,1	14,6	<0,718	9,39
Dibenz(a,h)anthracene	<1,82	<0,699	<0,718	<0,727
Dibenzothiophene	249	83,5	24,2	102
Fluoranthene	23,5	10,5	13,2	25,4
Fluorene	293	86,8	52,2	115
Indeno(1,2,3-c,d)pyrene	<2.03	<0.741	<0.718	<0.727
Naphthalene (in PAH-Mischungen)	562	297	353	422
Phenanthrene	316	108	118	231
Pyrene	39.7	15.5	11.8	29.5

Source: Rühl [2011]. Data from unpublished manuscript supplied by the Bitumen Waterproofers Association, and are available from BWA on request.

4. Exposures during Application and Removal of Bitumen Roofing Products

To understand the potential for exposure to bitumen fumes during the application of bitumen roofing products today, it is necessary to appreciate historical trends that have dramatically altered the industry's exposure profile over the past 30 years or so. Virtually all previous assessments of exposures to bitumen fumes in roofing have focused exclusively on hot-applied low-slope materials such as bitumen BUR. Cold-applied shingle and bitumen membrane products have been ignored, and little or no attention has been paid to soft-applied polymer modified bitumen products. This is perhaps understandable when the subject is bitumen fume exposures, because little or no exposure is expected in operations involving cold- and soft-applied products. But it does tend to paint a very misleading picture of the industry as a whole.

In the late 1970s and early 1980s, as the roofing industry had entered the early stages of its shift away from hot-applied bitumen products, NIOSH conducted a series of investigations of worker exposures in roofing application operations, including both traditional hot-applied BUR systems as well as newer systems utilizing soft- and cold-application methods. In one of the last in this series of surveys, the principal NIOSH investigator observed that "roofing operations have slowly evolved from almost total utilization of hot build up type systems such as petroleum asphalt and coal tar pitch to more recent innovations," including polymer modified bitumen and single ply systems, which are cold- and soft-applied [Zey 1986]. Summarizing the results of the series of exposure studies, Zey [1986] concluded that:

"Highest exposures have been encountered during application and tear off the older type build up roofs.

Environmental results obtained from previous and current roofing surveys indicate that for the newer type systems, potential safety hazards including falls from roofs, slips on slick roofing surfaces, and injuries from falling objects are probably more likely than over-exposures to roofing chemicals."

As developed below, most of the available data on potential inhalation and dermal exposures to bitumen or its constituents in roofing work pertain to the small and declining segment of the low-slope market that involves the use of hot bitumen in the installation of BUR and some SBS polymer modified bitumen roof systems. For the remainder of the roofing industry, the opportunities for such exposures in construction operations are limited or non-existent.

4.1 Cold-Applied Products and Systems

4.1.1 Shingles: As previously described, bitumen shingles are installed on steep-slope roofs using fasteners, typically roofing nails or staples that are driven into the roof deck with a hammer or a pneumatic gun. Steep-slope roof coverings are designed to be water-shedding rather than water-tight, and therefore are installed in overlapping rows that direct water down the slope of the roof to gutters without entering the lower elements of the roof system (underlayment, insulation, roof deck) or the structure itself. Because bitumen is not heated, there are no exposures to bitumen fumes during shingle installation.

On existing buildings the application of a new shingle roof typically first requires the removal of the existing roof. Old bitumen shingles are typically removed in an intact state using manual prying tools, and therefore measurable inhalation and dermal exposures to bitumen particulates are expected to be limited or non-existent. Because of the durability of the bitumen itself as well as of the reinforcing fiberglass felts used in today's shingle products, the materials are typically removed in large pieces without crumbling or pulverizing. U.S. regulatory reviews have found that significant exposures to bitumen particulates are far less likely on manual removal jobs with prying or slicing tools [EPA 1994b; OSHA 1995].

In a small-scale study of shingle tear-off workers sponsored by the U.S. bitumen roofing industry, about two-thirds of the benzene soluble particulate collected in worker breathing zones was below the analytical limit of detection, and the statistical mean exposure level was also below the LOD despite the assumption that all samples with results <LOD represented exposure at the LOD (Table 14) [Hill 2011]. To the extent that individual samples of worker breathing zones yielded detectable concentrations of benzene soluble particulates, the study data did not permit a conclusion that the exposures were asphalt particulates; other sources of benzene soluble particulate in the operations included other organic components of the shingles and roof substrate, as well as organic dust and debris observed on the roof surface prior to tear-off. Exposures determined as TP were higher on average and fewer were <LOD (Table 14), but the authors concluded that these exposures were predominantly inorganic in origin and therefore unrelated to asphalt particulates.

Likewise, skin contact with shingles during installation and removal is limited, particularly if workers wear gloves in accordance with industry recommended practices. Even in the absence of gloves, available studies on the percutaneous absorption of PAHs from highly viscous petroleum materials indicate that incidental skin contact with solid bitumen shingles is not likely to result in significant absorption of PAHs or other bitumen constituents [Potter 1999; Brandt 1999; Booth 1999].

4.1.2 Cold-Applied BUR and

Polymer Modified Bitumen Systems: As mentioned above, polymer modified bitumen systems may be cold-applied (using bitumen adhesives or peel-and-stick products), soft-applied (using torches or hot air welders), or hot-applied (using hot liquid bitumen). BUR systems traditionally have been hot-applied, but cold-process BUR systems using liquid bitumen adhesives are available.

In cold application operations using solvent-borne liquid bitumen adhesives, the bitumen sheets are unrolled on a layer of bitumen adhesive, which has been spread with a mop or squeegee without heating. The cold adhesive is usually a mixture of bitumen, filler and solvent (today, typically low aromatic mineral spirits). Because they do not require heating during application, there is no reason to expect volatilization of the constituents of the bitumen in these products. Worker inhalation exposures in these operations consist, instead, of vapors resulting from the evaporation of the solvent used in the products [NIOSH 2000]. In Europe, some polymer modified bitumen systems are mechanically affixed to the substrate. As in the case of shingles, these operations do not involve inhalation or dermal exposures to bitumen fumes.

4.1.3 Miscellaneous Liquid Products: As discussed above, straight-run and oxidized bitumens are the foundations for a broad variety of solvent-borne (cutback) and water-borne (emulsion) liquid and semi-liquid bitumen roofing products that are ready to use at ambient temperatures with no heating, including coatings, adhesives, cements, sealers, caulks and primers.

Cold-applied solvent-based products and emulsions are most commonly applied using hand tools such as brushes and trowels. As discussed above, NIOSH [2000] has indicated that the vapors released during such operations are expected to consist of the evaporating diluents and not the constituents of the bitumen used in these products. For higher-volume jobs, mechanical pumping devices are used

Table 14
Personal Time-Weighted Average Exposures to Particulates
Determined as TP and BSF During Shingle Tear-Off Operations

Exposure Metric	n	Number (Percent) Samples < LOD	Mean (mg/m ³)	Max (mg/m ³)
BSF	32	21 (65.6%)	<0.046 *	0.089
TP	32	8 (25%)	<0.49	1.4

* Where concentrations were below the limit of detection (LOD) (denoted by "<"), statistical analyses were based on the LOD reported by the analytical laboratory.

Source: Hill [2011]

to dispense liquid cutback or emulsion products, some of which use distribution nozzles that create a coarse spray. Spray operations account for approximately 5-10% of overall production volumes in this sector of the industry. Some spray applications, specifically primers, generate fine aerosols that may be inhalable. However, these products are typically used episodically in very short duration tasks, and represent an insignificant (less than 0.1%) share of total production of liquid bitumen products [RCMA 2008].

Regardless of application method, intermittent skin contact with cold-applied liquid bitumen products is expected to occur during application. No published studies have been found characterizing the extent and chemical composition of materials that might be percutaneously absorbed as a result of skin contact with cold-applied bitumen cutback or emulsion products used in roofing operations. Limited studies of bitumen and preparations containing bitumen indicate that dermal uptake of PAH is extremely low and influenced mainly by product viscosity and the type and PAH content of the diluent (solvent) employed in the preparation [AI 2011]. In addition, it is reasonable to expect that work practices, personal hygiene procedures and use of personal protective equipment would limit this route of exposure to bitumen. Common-sense precautions recommended by the bitumen roofing industry include the use of chemical resistant gloves and clothing, as well as splash goggles or face shields, if needed to avoid prolonged or repeated skin contact or eye contact, and the use of good personal hygiene practices, including washing skin and clothing that comes into contact with these materials.

4.2 Soft-Applied Bitumen Roofing Systems

As discussed previously, some polymer modified bitumen systems are soft-applied by using propane torches or hot air welders to heat the membrane sufficiently to ensure

Table 15
Bitumen Fume Exposures During Soft Application
of Polymer Modified Bitumen Membranes as Determined by US Methods*

Study	Method	n	Average Sampling Time	BSF			TOM		
				≤LOD	GM	Max	≤LOD	GM	Max
Zey [1986]	Previous NIOSH Methods	11	6.0 hrs	100%	≤LOD	≤LOD	n/a	n/a	n/a
Heritage Research Group [2007]	NIOSH/ Heritage	6	3.27 hrs	100%	≤LOD	≤LOD	100%	≤LOD	≤LOD
Kriech [2010]	NIOSH/ Heritage	13	3.9 hrs	62%	0.078	0.17	69%	0.87	1.38

* All concentrations are in mg/m³; ≤LOD includes results marked not quantifiable because sample concentrations were below field blanks.

Table 16
Bitumen Fume Exposures During Soft Application of Polymer Modified Bitumen
Membranes in Europe as Determined by German Methods

n	Location	Exposure Metric *	Min	GM ‡	50%	95%	Max
44	Germany	V + A †	0.05	0.39	0.31	0.31	6.40
44		Aerosol	0.05	0.22	0.25	0.17	2.79
33	6 countries	V + A	0.12	0.24	0.23	0.87	2.80
33		Aerosol	0.06	0.18	0.17	0.49	2.00
77	7 countries	V + A	0.05	0.32	0.25	2.79	6.40
77		Aerosol	0.05	0.21	0.17	1.20	2.79

* All exposures determined in accordance with IFA Method 6305 and reported in mg/m³.

† The sum of the measured aerosol and vapor fractions.

‡ Geometric mean.

Source: Rühl [2011]. Data from unpublished manuscript supplied by the Bitumen Waterproofers Association, and are available from BWA on request.

adequate adhesion to the other elements of the system. Torch jobs involve the use of assemblies made up of a propane tank, regulator, pressure gauge and high-pressure hose. The torch is used to heat the substrate and the bottom side of the polymer modified bitumen sheet as it is unrolled onto the substrate or a base sheet. Immediately after heating, the hot side of the sheet is rolled onto the substrate, which has the result of minimizing both the amount of heating needed and the amount of time available for emissions to emanate from the heated part of the sheet. Hot air welders, which are used in a similar fashion in installing polymer modified bitumen membranes, may be electrically powered or use a very short flame to heat the air as it is applied to the sheet.

In contrast to hot-applied bitumen jobs such as traditional BUR, workers using soft-application methods to install polymer modified bitumen membranes report limited or no visible emissions or odors associated with fumes. A NIOSH industrial hygiene study of the installation of a torch-applied polymer modified bitumen system found no detectable exposures to benzene soluble aerosol emissions and trace levels of two- and three-ring PAHs that are consistent with background levels typically found at roofing job sites [Zey 1986]. A pilot study conducted during the application of a torch applied SBS polymer modified bitumen roof found no detectable exposures to benzene solubles or total organic matter [Heritage Research Group 2005]. In the most recent study available [Kriech 2010], BSF results were below detection limits in 62% (8 of 13) workers using torches or gas heaters, with a maximum concentration of 0.17 mg/m³; for TOM determinations, 69% (9 of 13) samples were below the detection limit with a maximum concentration of 1.38 mg/m³. The results of these studies are presented in Table 14.

Rühl [2006, 2007, 2011] reported detectable aerosol and vapor concentrations during torch application of polymer modified bitumen sheets in Europe using IFA Method 6305. As shown in Table 16, the Rühl surveys found geometric mean aerosol concentrations \leq 0.22 mg/m³, below the reported limit of detection of 0.5 mg/m³. While this finding is consistent with the Zey [1986] and Heritage Research Group [2007] studies discussed above, Rühl found higher aerosol concentrations on some jobs (as indicated by the maximum concentrations in Table 16), as well as significant Vapor-Plus-Aerosol concentrations far above the TOM levels found in the U.S. surveys (Table 15), although not all U.S. surveys determined both vapor and aerosol concentrations.

As noted above (section 3.2.2), a recent field study comparing US and German methods has found that, for roofing operations, the German method generally yields higher measured aerosol concentrations and, in the case of TOM determinations, conversion factors can be used to compare

US results to data collected and analyzed using German methods. In addition, the task-related samples reported by Rühl [2006, 2007, 2011] cannot be compared directly to other studies presenting full-shift or nearly full-shift exposure data. In full-shift or nearly full-shift studies exposures were measured during both torching of bitumen membranes and during the exposure-free periods, a sampling strategy that yields lower reported exposures than task-related sampling [Raulf-Heimsoth 2011].

4.3 Hot-Applied Bitumen Roofing Systems

4.3.1 Operations Involving Exposures to Fumes:

As mentioned above, BUR and some SBS modified bitumen roofs can be hot-applied using oxidized bitumen heated until it reaches the viscosity needed to support proper adhesion of the membrane into the roofing system. The essential elements of hot-applied bitumen roofing installation are described in detail by NIOSH [2003], and are largely the same for each of these roofing systems with the exception of the number of layers, or “plies”, that are built into the roof membrane. Bitumen BUR systems typically have three to five plies. Polymer modified bitumen systems may have one or two plies (and polymer modified sheets are sometimes used as cap sheets in BUR roofs). Single-ply systems, of course, have just one ply.

Bitumen used in the construction of these systems is typically delivered to the jobsite as a solid, most often in the form of 15-45 kg cartons or “kegs.” When delivered in solid form, the bitumen is heated on-site in a roofing kettle and pumped to the roof for application through a supply line (often called the “hot pipe”) or brought to the roof in a bucket or can. In a few instances, the kettle is situated on the roof itself, eliminating the need for the hot pipe. Bitumen may also be delivered as a heated liquid transported in a tanker. Bitumen delivered by tanker may be heated to the proper temperature in the tanker and then pumped to the roof, or may first be transferred to a kettle for heating prior to pumping to the roof. Potential worker fume exposures related to operation of the kettle include both continuous exposure to fumes that escape from the kettle during operation, and intermittent exposures arising from the performance of particular operations that require the lid to be opened (i.e., filling, fluid and temperature checks, and skimming-off debris).

The hot bitumen delivered through the hot pipe is pumped into a container on the roof called a lugger. After delivery into the lugger, bitumen may be drawn directly into mop carts or buckets for manual installation jobs in which the bitumen is applied much like mopping a floor, or may be unloaded

directly into mechanical bitumen spreaders, or mechanical felt laying machines. In those jobs in which the kettle is situated on the roof, rooftop equipment such as mop carts and felt laying machines are loaded directly from a spigot on the kettle. In either case, potential worker exposures to fumes on the roof occur in the transfer of hot bitumen (e.g., from the lugger into a bucket), the escape of fumes from rooftop containers (e.g., luggers, mop carts and buckets, and the reservoirs on mechanical bitumen spreaders and felt laying machines), and during manual or mechanical application of hot bitumen to the roof surface.

4.3.2 Inhalation Exposures to Fumes: In general, exposures determined from worker personal breathing zone (PBZ) samples collected at BUR application worksites reveal significant variability in total particulate and soluble fraction concentrations [NIOSH 2000, 2003]. This should be expected in light of the outdoor, highly job-specific (non-systematized) nature of roofing work.

NIOSH conducted a number of industrial hygiene studies of roofers applying hot bitumen in the 1970s and 1980s. Airborne geometric mean fume concentrations (benzene, cyclohexane, or acetonitrile solubles) ranged from not detected to 2.1 mg/m³ [Brown 1977a, b, c; Hervin 1976; Reed 1983; Zey 1988; Tharr 1982a; Carson 1986]. Higher levels were found in a few other studies [Puzinauskas 1979; Brandt 1985; Schneider 1993; Suzi 1995]. Bitumen fume concentrations reported in more recent exposure assessments [Hicks 1995; Gamble 1999; Kriech 2004, 2007], summarized in Table 17, reveal individual geometric mean exposures ranging from 0.06 to 1.99 mg/m³ (benzene solubles). As shown in Table 18, the geometric mean of kettelman BSF exposures determined in a series of NIOSH studies of BUR jobs in 1998 and 2003-04 [Hayden 1998; Marlow 2003a, 2004a, e, f] was 0.69 mg/

m³; the corresponding value for rooftop workers was 0.53 mg/m³. In addition, Rühl [2006, 2007, 2011] has published exposure data for hot bitumen application jobs in Germany (job categories unspecified), reporting aerosol concentrations with a geometric mean of 1.31 mg/m³ and a maximum of 13.6 mg/m³ (Table 19). Rühl's data set consists of 104 samples of task related exposure and analyzed using the German Method IFA 6305. The German data represent both vapor and aerosols from task-related samples, which as already noted yields higher results than those obtained using U.S. methods measuring only the aerosol fraction of the exposure, particularly if shift-related sampling is used.

Because job nomenclature and crew responsibilities are not consistent across all studies, it is not possible to rank job tasks in hot-bitumen application jobs with respect to intensity of exposure, except that kettle operators are generally found to be the highest exposed workers [NIOSH 2000, 2003; Kriech 2004]. See Tables 17 and 18.

Table 17
Summary of US Bitumen Industry Exposure Studies of BUR Application Operations

Study	n	BSF [*]		TOM [*]		TP [*]	
		GM	Max	GM	Max	GM	Max
Radian [1991]							
Roofer	12	0.19	1.7	n/a	n/a	0.36	2.2
Laborer	5	0.30	0.62	n/a	n/a	0.38	0.91
Mechanic	7	0.26	1.80	n/a	n/a	0.54	1.2
Felt Mach. Oper.	7	0.21	2.4	n/a	n/a	1.0	2.5
Kettle Man	4	0.67	1.2	n/a	n/a	1.0	1.6
Mop Man	3	0.21	0.75	n/a	n/a	0.51	1.2
EBSI [1997]							
Foreman	6	0.12	0.34	0.34	3.21	0.22	0.77
Kettelman	4	0.15	0.48	0.15	2.39	0.27	0.72
Laborer, Misc	7	0.06	0.22	0.44	6.71	0.17	0.35
Mop Man	7	0.16	0.39	0.41	1.19	0.30	0.54
Roof Laborer	34-37	0.13	1.23	0.28	3.79	0.44	0.54
Kriech [2004][†]							
Lugger	3	0.59	0.89	1.52	2.66	1.35	2.05
Kettelman	5	1.99	9.63	5.07	11.80	2.69	10.30
Mopper	7	0.19	0.59	1.37	2.51	0.76	1.44
Layer	6	0.21	1.02	1.30	3.07	1.26	2.81
Laborer/Supervis.	5	0.23	0.71	0.82	1.30	0.72	0.93
Kriech [2007]							
Kettelman	4	0.53	1.12	n/a [‡]	n/a [‡]	1.02	1.43
Rooftop Worker	12	0.27	0.72	n/a [‡]	n/a [‡]	0.43	0.91

^{*} All concentrations are geometric mean (GM) or maximum (Max) 8-hour time weighted average PBZ concentrations in mg/m³, except Kriech [2004] reports task exposures that are likely to overstate 8-hour TWAs.

[†] Exposures higher than other comparable studies due to effort to identify highly-exposed workers and differences in sampling methodology [Kriech 2004].

[‡] Kriech [2007] reports average TOM TWA concentrations of 3.0 mg/m³ for kettle workers and 2.02 mg/m³ for rooftop workers.

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Table 18
Summary of Post-1998 NIOSH Industrial Hygiene Surveys of Uncontrolled BUR

Installation Operations				
Job Category	Sample Time (minutes)	TP Conc. (mg/m³)	BSF Conc. (mg/m³)	Total PAC Conc. (ug/m³)
<u>Marlow [2003a]</u>				
Kettleman	494	1.92	1.11	233
Kettleman	492	3.15	2.74	585
Mopper	478	0.85	0.58	98.6
Mopper	478	0.41	0.26	49.4
Mopper	470	2.03	0.87	192
Mopper	463	0.30	0.24	40.7
Lugger	472	2.44	2.12	313
Lugger	472	0.77	0.42	140
<u>Hayden [1998]</u>				
Kettleman	398	1.11	0.73	185
Rooftop Worker	132	0.75	0.42	130
Rooftop Worker	126	0.96	0.50	133
Rooftop Worker	131	1.61	1.31	278
Rooftop Worker	58	0.61	0.38	72
Rooftop Worker	243	0.56	0.28	54
Rooftop Worker	247	0.95	0.40	137
Rooftop Worker	245	1.13	0.89	9
Rooftop Worker	238	1.74	1.08	234
Rooftop Worker	192	0.69	0.26	58
<u>Marlow [2004a]</u>				
Kettleman	400	0.25	<0.05	6.04
Kettleman	482	0.41	0.12	24.7
Kettleman	554	0.78	0.2	36.4
Rooftop Worker	234	0.18	<0.09	14.2
Rooftop Worker	322	0.38	0.2	53.4
Rooftop Worker	321	0.14	<0.06	<1.10
Rooftop Worker	310	1.1	0.63	128
Rooftop Worker	305	0.5	0.2	35.5
Rooftop Worker	305	0.8	0.32	80.5
Rooftop Worker	332	0.25	<0.06	10
Rooftop Worker	200	0.16	<0.10	18.6
Rooftop Worker	391	0.28	0.13	n/a
<u>Marlow [2004e]</u>				
Kettleman	430	3.85	3.44	679
Kettleman	348	1.77	1.47	237
Kettleman	465	2.59	1.9	215
Kettleman	438	0.5	0.36	96
Rooftop Worker	212	1.33	0.95	20
Rooftop Worker	205	2.09	1.82	455
Rooftop Worker	152	3.01	1.75	507
Rooftop Worker	145	0.65	0.46	183
Rooftop Worker	147	1.14	1.07	221
Rooftop Worker	144	1.20	1.12	284
Rooftop Worker	235	0.67	0.48	96
Rooftop Worker	270	0.37	0.35	79
<u>Marlow [2004f]</u>				
Kettleman	279	0.39	0.13	10.9
Rooftop Worker	192	1.45	0.04	244
Rooftop Worker	193	7.24	5.95	1018
Summary Statistics				
	N	TP	BSF	PACs
<u>Kettlemen</u>				
Geometric Mean	11	1.06	0.69	94
Maximum	11	3.85	3.44	679
<u>Rooftop Workers</u>				
Geometric Mean	34	0.78	0.53	96
Maximum	34	7.24	5.95	1018

4.3.3 Inhalation Exposures to PAHs:

Exposures to polycyclic aromatic hydrocarbons (PAHs) have also been evaluated at roofing sites [Hatjian 1995, 1997; Hicks 1991, 1995; Kriech 2007]. In studies employing GC/MS analysis, two- and three-ring PAHs account for a substantial majority (~85%) of the measured PAH exposure. Table 20 displays the PAH concentrations recently found in fumes generated according to the Fraunhofer protocol [Preiss 2006; Pohlman 2006] and matched against industrial hygiene measurements taken in four field operations involving application of oxidized Type III BUR manufactured from commercially representative U.S. crude sources. Average kettle temperatures in the studies ranged from 271-276°C (520-529°F), and average mop bucket temperatures ranged from 224-238°C (436-460°F). PAH levels in bitumen are generally 100 to 1,000 times lower than coal tar [Brandt 1985; Machado 1993; NIOSH 2000].

4.3.4 Dermal Exposures to Fumes:

As discussed in van Rooij [2007], a number of studies have examined the percutaneous absorption of bitumen fumes [e.g., McClean 2002; Knecht 2001]. In BUR application work, dermal exposure to condensed bitumen fumes has been examined using skin wipes. Hicks [1995] collected post-shift dermal wipe samples from workers at BUR sites and analyzed for 16 unsubstituted PAHs, finding detectable levels of only one PAH, naphthalene.

A recent industrial hygiene assessment [McClean 2007] used dermal patches to estimate skin exposures of roofers to PAHs in bitumen fumes during hot application of BUR systems. As summarized in Table 21, the results for individual PAHs (pyrene and B[a]P) were consistent with previous studies, and on-roof workers were found to have higher dermal exposures. This and other considerations led the authors to conclude that particulate exposures from the tear-off phases of these jobs may have affected the quantitative findings. (See Section 4.4 for more discussion of dermal exposures arising from particulates created during tear-offs.)

Table 19
Summary of German Bitumen Forum Surveys of Hot Bitumen Pour-and-Roll Roof Application Operations

n	Location	Exposure Metric *	Min	GM ‡	50%	95%	Max
104	Germany	V + A †	0.25	2.57	2.4	9.8	18.2
104		aerosol	0.22	1.31	1.2	5.3	13.6

* All exposures determined from task-related sampling in accordance with IFA Method 6305 and reported in mg/m³.

† The sum of the measured aerosol and vapor fractions.

‡ Geometric mean.

Source: Rühl [2011]. Data from unpublished manuscript supplied by the Bitumen Waterproofers Association, and are available from BWA on request.

Table 20
Individual PAHs Detected in the Tank Fume Condensates Matched Against Industrial Hygiene Field Samples of Hot BUR Operations

PAH	Type III Bitumen BUR Samples			
	A	B	C	D
Acenaphthene	18	86	19	23
Anthracene	23	62	16	11
Benz[a]anthracene	12	26	12	9
Benzo[a]pyrene	3.1	7	1.6	1.2
Benzo[b]fluoranthene	2.8	4.9	2.7	2.1
Benzo[e]pyrene	8.1	12	6.9	5.7
Benzo[g,h,i]perylene	2.0	1.9	1.2	0.99
Benzo[k]fluoranthene [†]	1.9	3.5	1.5	1.7
Chrysene	14	16	12	11
Fluoranthene	6.8	89	11	6.9
Fluorene	110	180	69	94
Indeno[1,2,3-cd]pyrene	0.87	1.1	0.74	0.63
Naphthalene	110	210	77	140
Phenanthrene	130	370	70	51
Pyrene	25	180	14	10
Triphenylene	3.9	8.6	3.9	3.0
Total PAHs	471	1258	319	371

Source: Kriech [2007]. Results are in mg/kg.

[†] Benzo(k)fluoranthene and benzo(j)fluoranthene coelute.

Table 21
Skin Exposures to PAHs During BUR Application Operations Using Hot Bitumen as Determined by Dermal Patches

	(ng/cm ²)								
	PAC [§]			Pyrene [§]			Benzo[a]pyrene [§]		
	n	GM	Max	n	GM	Max	n	GM	Max
Roof Workers	56	344	21,437	55	3.8	150	54	1.0	59
Kettlemen	19	299	4,558	19	4.5	34	18	0.9	20

Source: McClean [2007]

[§] Method limits of detection (in ng/cm²) were 25 for PACs; 2.4 for pyrene; and 0.5 for B[a]P.

4.3.5 Fume Exposure Control Measures:

Cooperative efforts by NIOSH, the United Union of Roofers, Waterproofers and Allied Workers, and the U.S. bitumen roofing industry to identify and evaluate methods to control fume exposures during operations involving hot bitumen have led to a series of publications describing effective options for the control of inhalation and dermal exposures to bitumen fumes. Among the results of this collaboration are two NIOSH publications – a technical review [NIOSH 2003] and a brochure for contractors and roofing workers [NIOSH 2007]. They provide information on available fume exposure control options to assist in the selection of exposure-control strategies on a job-specific basis to fashion practical and effective solutions considering the wide variabilities in environmental, operational, economic and other factors that characterize roofing work. The menu of available control measures identified by NIOSH includes the following:

4.3.5.1 Material Substitution: Fume-suppressing BUR bitumens, which are made by adding small amounts of polymer to the bitumen, have been shown to reduce worker fume exposure in a variety of studies and are available on the market [U.S. Patents 6,069,194; 6,107,373; 6,130,276; 6,488,988]. Some of the polymer separates from the bitumen and forms a floating skim on the surface of the bitumen in the kettle. Results from a series of field studies indicate that fume-suppressing bitumens significantly reduce fume emissions and worker exposures and suppress the emanation of 3- to 7-ring PACs from the bitumen. Marlow [2003b] reports average reductions in NIOSH evaluations of this technology of 75% total particulate exposure, 85% benzene soluble exposure, and 77% PAC exposure for kettle workers, with all being significant at 95% confidence levels [Franzen 2000; Marlow 2001, 2002, 2003a; Kriech 2004; NIOSH 2007].

4.3.5.2 Kettle Temperature Control Practices: As discussed in Section 2.2 above, there are marked differences in the way bitumens respond to temperature. Consequently, the quantitative or qualitative relationships between temperature and fume emission rates or fume composition of any one bitumen may differ substantially from the temperature-fume relationships of other bitumens with different physical properties. Thus, fumes generated at such temperatures exhibit far more quantitative and qualitative similarities than differences despite the wide range of temperatures needed to render bitumens with markedly different physical properties suitable for use in commercial operations [Hicks 1995; Gamble 1999; Kriech 2007].

Nevertheless, a number of studies involving bitumen heated in laboratory and static field settings (the headspace of storage tanks) have reported that, for any one type of bitumen, higher temperatures can be associated with higher

rates of airborne emissions [Thayer 1981; Machado 1993; McCarthy 1999; Brandt 1999; Reinke 1993, 2000; Franzen 2000]. One study found that a 28°C reduction in kettle temperature was associated with a 38-59% reduction in BSF exposures at the kettle [Kriech 2004]. The relationship between temperature and the composition of emissions from hot bitumen is less clear: Some studies indicate that higher processing temperatures are associated with the presence of higher molecular weight, lower volatility compounds [McCarthy 1999; Kriech 2004], while others have produced inconsistent results or found no relationship at all [Thayer 1981; Machado 1993; Reinke 1993, 2000; Law 2005].

In addition, a series of NIOSH and industry publications discuss in depth the safety and product performance considerations that make temperature control an important operational objective in hot BUR application jobs [NRCA 1991; ARMA 1993a, b; NIOSH 2003]. To achieve proper adhesive levels the bitumen must be at the proper viscosity and hence the right temperature. Overheating can degrade the properties of the bitumen due to a phenomenon known as “fallback”, and overheating near or past the flash point can also cause fires.

For all these reasons, temperature controls are a key element of NIOSH and industry exposure control recommendations for BUR application jobs [NIOSH 2003, 2007; NRCA 2004].

4.3.5.3 Work Practices, Personal Protective Equipment, Training and Education: The suite of fume exposure control alternatives in the NIOSH [2003, 2007] guidelines includes recommended work practices, personal protective equipment, education and training.

4.3.5.4 Kettle Engineering Controls: These include temperature controls such as thermostats with automatic shut-off systems to prevent over-heating. In addition, kettle control systems include emission capture and destruction devices; loading devices allowing the kettle operator to refill the kettle without opening the lid; and afterburner and filtration systems for processing the fumes collected from the headspace inside the kettle. NIOSH evaluations of these systems have produced inconsistent results and have observed that these systems need to be carefully evaluated to ensure that the risks of fires and explosions are adequately controlled [Hayden 1998; Marlow 2004a-f; NIOSH 2007].

A comparable process has taken place in Europe. For example, Germany’s statutory accident and insurance prevention institution for the building trade (Bauberufsgenossenschaft BGBau), the roofers association (ZVDH) and association of bitumen sheet producers (Industrieverband Bitumen Dach- und Dichtungsbahnen e.V.,vdd), have developed

several guidance documents to reduce and control kettle temperatures [BGBau 07/2010, ref.-no.:BG 656]. Similar guidelines have been developed by Stichting Bedrijfstakregekingen Dakbedekkingsbranche (SBD) in the Netherlands, and by OPPBTP and CSFE in France.

These guidelines provide that, although kettle volumes are not restricted, (i) volumes greater than 30 liters must have thermometers attached to the kettle; (ii) volumes greater than 50 liters must use additionally a thermostat which automatically shut off the heating system at a fixed temperature to avoid overheating; and (iii) kettles with a volume greater than 50 liters must be equipped with an additional flame monitor. Normal kettle sizes in Europe are 100 liters or more. Kettles must be placed in a reservoir large enough to hold the kettle volume in case of a leak. In addition, roofers are to be advised to wear gloves during the hot application operations to protect themselves in respect of skin contact with the hot bitumen (skin burns).

4.4 Particulate Exposures during Tear-offs of Existing Bitumen Roofs

As previously discussed, workers installing low-slope roof systems, whether or not they are bitumen systems, will often be called upon to first remove the old roof. If the old roof is a BUR or polymer modified bitumen membrane system, the removal operation, called a “tear-off” in the roofing trade, may create airborne bitumen particulates that can be inhaled or be deposited on the skin. Existing low-slope membrane-type roofs can be removed using slicing or prying hand tools such as pry bars, axes, or shovels; power equipment such as power roof cutters and power tear-off machines that pulverize narrow channels of the membrane as they cut it into squares for manual removal; or more aggressive hand tools such as hand saws that also create airborne particulates.

Inhalation exposures to bitumen particulates have been evaluated in several NIOSH Health Hazard Evaluations. Total particulates in worker breathing zones have ranged from non-detectable to 2.84 mg/m³, while benzene solubles have been found at concentrations up to 0.80 mg/m³. PAHs have either been below the limits of detection or found at trace levels less than 0.1 ug/m³, far below the levels that have been found for removal of coal tar roofs (see Section 4.5, below) [Zey 1988; Reed 1986]. Tear-off operations involving bitumen-based BUR systems also involve skin contact with particulates. Urinary 1-hydroxypyrene data suggest percutaneous absorption of PAHs may accompany this contact [McClellan 2007], although confounders may explain these findings and further study is needed.

As discussed above (section 4.1.1), no data have been found

suggesting that removal of bitumen shingles using manual prying tools involves significant inhalation or dermal exposures to bitumen particulates.

4.5 Co-Exposures to Toxic Substances

Workers in bitumen roofing operations may be exposed to a number of other substances that may be of interest in any effort to evaluate the potential for adverse health effects, or to establish the presence or absence of associations between exposure and health effects in retrospective studies of roofing workers. Potential co-exposures in the roofing industry, either historically or currently, include coal tar, diesel exhaust, PAHs from other sources including diet and tobacco use, fibers and dusts (e.g., asbestos, silica), and hydrocarbons (e.g., benzene, gasoline). Co-exposures to coal tar have been empirically documented and proven to be an especially difficult problem in the roofing industry because coal tar and bitumen are similar in appearance, physical properties and commercial uses (particularly in the past), and many studies of roofing workers (again, particularly older studies) have not distinguished between the two materials [IARC 1985; NIOSH 2000; ACGIH 2001; Wess 2004]. Despite these similarities, substantial differences in chemical composition and potential health effects are universally recognized [AI 2011].

The potential role of co-exposures to coal tar and other potentially relevant toxic substances in the U.S. and European roofing industries has been evaluated in detail in recent studies [Boffetta 2001, 2003a,b; Mundt 2007; Fayerweather 2007; Priha 2007]. The results are summarized below.

4.5.1 United States: Mundt [2007] estimates that the prevalence of coal tar in roofing was about 40% in the 1970s and about 10% in the early 1980s. Although coal tar use has declined dramatically in the U.S. since the 1980s, a significant potential for coal tar exposure remains today from re-roofing jobs that involve the tear-off of existing coal tar roofs. Because the useful life of BUR systems often exceeds 30 years, a sizeable number of coal tar BUR systems constructed in the 1980s and previously remain in the inventory of existing built-up roofs. In addition, coal tar continues to have a small presence in the U.S. market for new or replacement roofs – less than 1% of the overall roofing market for 2006 [NRCA 2007a] – predominantly on structures subject to government specifications (e.g., DOD [1995, 2006], NAVFAC [2005], UFGS [2006a,b], USACE [2008]).

Industrial hygiene assessments have found measurable exposures to PAHs during coal tar pitch BUR application operations, including B[a]P and other four- to six-ring compounds [IARC 1985; Hammond 1976; Herwin 1976a, b; Zey

1988; Fayerweather 2007]. NIOSH exposure studies likewise have found measurable concentrations of PAHs, including B[a]P and other higher molecular weight PAHs, during coal tar pitch BUR tear-offs [Hervin 1976b; Tharr 1982a; Reed 1983; Behrens 1985; Zey 1988]. NIOSH investigators [Tharr 1982a] have observed that exposures to polycyclic organic matter during coal tar tear-offs are higher than exposures during hot coal tar pitch application operations, and that coal tar tear-offs differ markedly from bitumen roof tear-offs, which typically involve trace or non-detectable exposures to PAHs [Brown 1977b; Tharr 1982b; Reed 1986; Zey 1988]. Recent investigations indicate that dermal exposure to particulates generated during the removal of these roofs can result in significant systemic absorption of unsubstituted PAHs [McClellan 2007].

Mundt's investigation also found data indicating that although asbestos use was largely eliminated in roofing materials by 1980, as recently as 1994 20% of installed BUR felts and over 90% of flashings, coatings, cements and mastics on commercial low-slope roof jobs contained asbestos. Use of asbestos in the U.S. roofing industry has since been discontinued, except for limited use in certain liquid-applied adhesives. Again, because of the longevity of BUR systems, roofing workers may continue to encounter asbestos-containing materials in the context of tear-off operations. The question of whether workers may be exposed to free asbestos fibers in these operations, however, remains a subject of scientific debate. U.S. regulatory findings indicate that the potential for exposures to asbestos in roofing work is influenced by the type of roofing material, its condition (friability) at the time of removal, and the tear-off practices used [EPA 1994b; OSHA 1995].

A number of other exposures in the roofing industry have been identified, including Stoddard solvent, fiberglass, silica and formaldehyde, diesel exhaust (mainly ground crew), and benzene or kerosene (hot moppers and cleaning crew). Similar exposures were found on a more limited basis during roofing manufacturing [Mundt 2007].

4.5.2 Europe: Co-exposures to toxic substances among European bitumen workers, particularly coal tar, have been studied in depth in connection with the ongoing IARC multi-country epidemiology study of European bitumen workers [Boffetta 2001, 2003a,b].

Interest in coal tar as a potentially significant confounder in studies of roofing workers took hold when Partanen [1994] noted that bitumen roofers were often exposed to coal tar and proffered the "plausible assumption" that PAHs from tar pitch contributed to the observed excess cancer risk in roofers. Occupational exposures to asbestos were also mentioned as a possible contributor to excess lung cancer risks in roofers [Partanen 1994]. Because of the significance of potential confounding exposures to coal tar, the investigators involved in the recently-completed IARC Cohort Study [Boffetta 2001, 2003a,b] collected data on co-exposures to coal tar among the workers included in the IARC multi-country cohort [Burstyn 2003].

Fayerweather [2007] summarizes the findings, shown below in Tables 22 and 23. The IARC investigators concluded that the data on coal tar exposures collected in connection with the cohort study probably underestimate actual exposures, and this was one of the considerations that led IARC to conduct a follow-up case-control study based on a more thorough investigation of exposures to coal tar and other potential confounders [Boffetta 2003a]. While the coal tar exposure data collected by the IARC investigation specifically relates bitumen paving workers, the IARC investigators found that coal tar use in other segments of the European bitumen industry reportedly followed the same pattern, and accordingly assumed coal tar exposures to have the same intensity in all job classes [Burstyn 2003].

Table 22
Prevalence of Coal Tar Exposure of European Bitumen Workers by Country and Time Period

<u>Country</u>	<u>1950s-1960s Coal Tar Prevalence</u>
Denmark	90%
Norway	3%
Sweden	20%
Finland	1%
Netherlands	40%
Germany	20%
France	1%
Israel	1%

Source: Fayerweather [2007]

Table 23
Prevalence of Coal Tar Exposure of European Bitumen Workers
Based on Person-Years of Exposure to Coal Tar

<u>Country</u>	<u>Coal Tar Person-Years of Worker Exposure</u>	<u>Total Person-Years of Observation</u>	<u>% of Cohort's Total Person-Years that Involved Coal Tar Exposure</u>
Denmark	117,986	212,300	55.6%
Norway	20,431	177,205	11.5%
Sweden	47,220	375,875	12.6%
Finland	15,568	97,529	16.0%
Netherlands	28,478	55,020	51.8%
Germany	7,781	82,240	9.5%
France	97,047	170,870	56.8%
Israel	0	45,404	1%

Source: Fayerweather [2007]

Quartz was commonly used as surfacing material for bitumen membranes in both countries from 1950 to 2005. Quartz sand is mainly used for base layer waterproofing membranes and on the bottom layer of roofing membranes while quartz-rich slates are commonly used on the top layer of roofing membranes. Exposure to crystalline silica from quartz dust among production line workers was estimated to be very high until the 1980, and it can still be considered to be high when compared with the current occupational exposure limit values [Priha 2007].

4.5.3 Lifestyle Factors:

More recently, Priha and colleagues at the Finnish Institute of Occupational Health published a retrospective study of the exposures of Danish and Finnish bitumen roofing workers to carcinogenic substances during the period of 1950 to 2005. The investigation found that asbestos, coal tar pitch and quartz dust were commonly used in the field during the period under study. Formaldehyde and diesel exhaust were also used, but exposure to these agents was found to be low [Priha 2007].

Lifestyle factors are also relevant to any assessment of retrospective studies as well as the current health status of workers. For example, as discussed in Appendix E [Shanahan 2008], roofers have the highest smoking rate among any occupation or trade, including any other construction trade [Shanahan 2008; Mundt 2007].

Asbestos was used as filler in bitumen membrane manufacturing in Finland during the 1970s and in Denmark until the mid-1980s. In addition, asbestos was used as bitumen membrane surfacing material in Finland until the mid-1970s. Asbestos has also been added to some bitumen adhesives and emulsions in both countries. Priha et al. [2007] estimated exposure to asbestos among production line workers to be high in Finnish factories where asbestos was used in certain operations until the mid-1970s.

4.6 Emissions Data

Coal tar pitch was used for roofing felt production both in Finland and in Denmark until the mid-1960s. Coal tar and coal tar pitch have been used also for waterproofing foundations and interior spaces in the 1950s, and in roof treatment products until the mid-1980s. Exposure of production line workers to coal tar pitch volatiles was estimated by Priha et al. [2007] to have been high in the factories where coal tar pitch was used until the mid-1960s. The exposure of roofers/waterproofers may have been significant until the 1960s. The investigators also found some evidence of exposures to benzene.

Bitumen emissions from roofing kettles are influenced by a variety of factors, including the physical properties of the bitumen; the type of bitumen (Types I through IV); the temperature range at which the kettle is operated; operational practices including bitumen throughput, frequency and duration of opening of the kettle lid; the presence, use and efficiency of emission controls; the use of fume suppressing bitumens; and environmental factors. A number of studies have sought to characterize kettle emissions or have produced data that are relevant to such an effort. However, because of the varying methodologies used and the inability to measure emissions across the full range of field conditions or to develop a model validated as representative of these conditions, the available data should be considered as qualitative evidence of the potential chemical composition of emissions.

Differences in sampling methodologies present an obstacle to quantitative analysis of studies reporting data that might be considered relevant to characterizing kettle emissions. At one end of the spectrum are industrial hygiene surveys that have included stationary air samplers positioned at various locations near operating roofing kettles in efforts to generate

surrogate measures of worker breathing zone concentrations (e.g., Marlow [2003a]; Kriech [2004]). In addition to the influence of environmental factors, both distance from the kettle emission source and the height of the sampler likely significantly influenced the emission rate and composition findings. At the other end of the industrial hygiene spectrum is a study that located the sampler in the direct exhaust path of a hood vent installed on a kettle for the purpose of capturing emissions [Legend 1997]. In this case the data were presumably influenced by the flow rates and capture efficiencies of the kettle control vent hood.

Other studies have collected samples in the headspace of storage tanks operated at specific temperatures (e.g., Kriech [1999]), in a specially constructed burn hut enclosing a stainless steel bowl containing heated BUR bitumen intended to simulate a kettle [EPA 1991], and from kettle vent openings during heating of BUR bitumen in commercial kettles described as typical (Puzinauskas [1979], Hildemann [1991], Rogge [1997]). Franzen [2000] sampled emissions from a kettle in a partially enclosed area intended to minimize environmental variabilities but otherwise to mimic field kettle operations.

Although the disparate sampling methodologies prevent straight-on comparisons of fume emission rates among these studies, the findings on the chemical composition of kettle emissions are broadly consistent. EPA [1994] used the 1991 burn hut study to derive kettle emission factors for volatile organic compounds. It is likely that the significant decline in the use of hot-applied bitumen roofing systems over the past 20 years has led to an overall reduction in aggregate VOC and aerosol/particulate emissions from roofing kettles.

5.0 Concluding Summary

As developed above, today's global bitumen roofing industry is diverse, encompassing a broad range of products with varying physical properties that are installed using methods that have dramatically different fume exposure potential. Both straight-run and oxidized bitumens processed to a wide range of softening points are used to meet widely disparate physical performance specifications as required for their various end uses. The overwhelming majority of modern roofing bitumen products are applied "cold" (at ambient temperature) in the field, and do not entail exposures to fumes, or using "soft" application methods that generate far lower fume concentrations than hot-applied products. BUR and other hot-applied systems, once dominant in the industry, today hold only 6% of the total North American/European bitumen roofing market.

As a result, the roofing industry operations of primary interest with regard to bitumen fume exposures are bitumen roofing product manufacturing plants and hot-application roof construction jobs. As shown above, exposures in manufacturing facilities have declined markedly over the past 30 years as the result of product, process and emission control innovations. In the low-slope roof construction sector, the strong trend toward product diversification over the past few decades is rapidly diminishing the prevalence of contractors and workers who exclusively engage in hot bitumen operations. At the same time, cooperative Government-Labor-Industry investigations have identified a suite of product, equipment and work practice controls that can effectively reduce fume exposures on hot bitumen application jobs.

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GLOSSARY

%m: Percent by mass. The mass of material reflects the quantity of matter within a sample.

%w: Percent by weight. Weight is defined as the mass multiplied by the force of gravity (Earth gravity is approximately 9.8m.s-1).

ACID MODIFIED ASPHALT/BITUMEN: Bitumen modified by the addition of inorganic acids, typically phosphoric, or polyphosphoric acid.

AIR BLOWING: The process by which compressed air is blown into a BITUMEN feedstock typically at 230-260°C (446–500°F), sometimes in the presence of catalysts (typically ferric chloride, phosphoric acid, or phosphorus pentoxide). This process results in complex reactions which raise the softening point and viscosity of the bitumen. See OXIDISED BITUMENS.

AIR-BLOWN ASPHALTS: See OXIDISED BITUMENS

AIR-BLOWN BITUMENS: BITUMEN products produced by AIR BLOWING. See OXIDISED BITUMENS.

AIR-REFINED BITUMENS: Penetration bitumens produced by partial blowing. Archaic term, no longer in use.

AIR-RECTIFIED BITUMEN (synonym SEMI-BLOWN BITUMEN): A bitumen that has been subjected to mild oxidation with the goal of producing a bitumen meeting paving grade bitumen specifications Air rectified bitumens are used in paving applications as well as roofing applications, such as shingle saturants and Type 1 Built Up Roofing Asphalt (BURA), and also for some industrial applications

ASPHALT: A mixture of BITUMEN and mineral materials used as a paving material that is typically produced at temperatures in the range of 140-160°C (280-320°F). In North America the term ASPHALT is synonymous with BITUMEN as used in Europe and also the term HOT MIX ASPHALT.

ASPHALT BINDER: Term used in the U.S. and some other countries for BITUMEN.

ASPHALT CEMENT: Term used in the U.S. and some other countries for BITUMEN.

ASPHALT COLD MIXES: ASPHALT mixtures made using CUTBACK BITUMENS or BITUMEN EMULSIONS, which can be placed at ambient temperatures.

ASPHALTENES: Highly polar aromatic materials.

Asphaltenes have high viscosity or stiffness at ambient temperatures and are responsible for the overall stiffness of BITUMENS. They can be precipitated with n-heptane and are sometimes referred to as n-heptane insolubles.

ASPHALT MIXES (MIXTURES): Mixtures of graded mineral aggregates (sized stone fractions, sands and fillers) with a controlled amount of PENETRATION GRADED BITUMEN.

ATMOSPHERIC DISTILLATION: Distillation at atmospheric pressure

ATMOSPHERIC RESIDUE: Residue of ATMOSPHERIC DISTILLATION

BASE OILS: Petroleum-derived products consisting of complex mixtures of straight and branch-chained paraffinic, naphthenic (cycloparaffin) and aromatic hydrocarbons, with carbon numbers of 15 or more and boiling-points in the range of 300–600°C (570–1110°F). Depending on climatic conditions BASE OILS can be used to reduce the low stiffness of BITUMENS to resist low temperature cracking of pavements.

BENDING BEAM RHEOMETER: A machine used to determine the low temperature stiffness properties of BITUMENS that have been laboratory aged to simulate extended aging of the BITUMEN in ASPHALT pavements. Results are part of the PERFORMANCE GRADED BITUMEN specification

BINDER: According to EN12597; Material serving to adhere to aggregate and ensure cohesion of the mixture. A more general term used to identify BITUMEN plus potential modifiers used to produce ASPHALT mixes. The term BINDER reflects that some ASPHALT mixes may utilise MODIFIED BITUMENS.

BITUMEN BLOCKS: Small size blocks (typically 20kg) of BONDING BITUMEN for being melted in kettles

BITUMEN, PETROLEUM DERIVED: A dark brown to black cement-like residuum obtained from the distillation of suitable CRUDE oils. The distillation processes may involve one or more of the following: atmospheric distillation, vacuum distillation, steam distillation. Further processing of distillation residuum may be needed to yield a material whose physical properties are suitable for commercial applications. These additional processes can involve air oxidation, solvent stripping or blending of residua of different stiffness characteristics.

GLOSSARY

BITUMEN EMULSION: A mixture of two normally immiscible components (BITUMEN and water) and an emulsifying agent (usually a surfactant). Bitumen emulsions are utilised in paving, roofing and waterproofing operations. These materials are called EMULSIFIED ASPHALTS in North America.

BITUMEN FUME: The gases and vapours emitted from heated BITUMEN, and the aerosols and mists resulting from the condensation of vapours after volatilisation from heated BITUMEN.

BITUMEN GRADING TERMINOLOGY: There are currently three main grading systems employed worldwide for identifying and specifying bitumens used in road construction. These systems are PENETRATION, VISCOSITY and PERFORMANCE GRADED. Although each system has test methods that are unique to that system, similar bitumens are used across all grading systems. The particular system used within a given country or region is generally a result of historical practices or governmental stipulations.

BITUMEN ENAMEL (BITUMEN PAINT): An external coating for protecting steel pipes. The term can also be used for bitumen paints (formulated CUTBACK BITUMENS or BITUMEN EMULSIONS)

BITUMEN MACADAM: A type of ASPHALT mix with a high stone content and containing 3–5% by weight of bitumen

BITUMEN PAINT: A CUTBACK BITUMEN made to treat bare metal or concrete or wood surfaces giving a bond between the surface and an ENAMEL or a bituminous membrane or bonding bitumen

BITUMEN PAINT: A specialised CUTBACK BITUMEN product that contains relatively small amounts of other materials that are not native to BITUMEN or to the diluents typically used in cutback products, such as lampblack, aluminum flakes, and mineral pigments. They are used as a protective coating in waterproofing operations and other similar applications.

BITUMEN PRIMER: A CUTBACK BITUMEN made to treat bare metal surfaces giving a bond between the metal and an ENAMEL

BITUMEN ROOFING FELT: A sheet material, impregnated with BITUMEN, generally supplied in rolls and used in roof construction.

BITUMINOUS: Of or related to BITUMEN. In this document

the terms BITUMEN and BITUMINOUS refer exclusively to petroleum derived BITUMEN as defined above.

BLENDED BITUMENS: Blends of two or more BITUMENS with different physical characteristics or blends of Bitumen(s) and high boiling point petroleum fractions (e.g. Heavy Vacuum Gas Oil) in order to achieve desired physical properties

BLOWING STILL: (Also known as OXIDISER or Bitumen Blowing Unit.) Equipment used to air blow BITUMEN.

BONDING BITUMEN: OXIDISED BITUMEN or POLYMER MODIFIED BITUMEN used for HOT APPLIED ROOFING

BRIQUETTE: See BRIQUETTING. Archaic term, no longer in use

BRIQUETTING: The process by which fine materials (e.g., coal dusts, metal tailings) are mixed with a bitumen (or other) binder to form conveniently handled blocks or pellets. Archaic term, no longer in use.

BUILT UP ROOFING (BUR) NORTH AMERICA: A continuous roofing membrane consisting of plies of saturated organic (e.g., cellulose) felts or coated inorganic (e.g., glass fiber) felts, assembled in place with alternate layers of BITUMEN or COAL TAR PITCH, and surfaced with mineral aggregate, a granule surfaced sheet, or a roof coating.

EUROPE: A continuous roofing membrane consisting of plies of coated inorganic (e.g., glass fibre) felts, assembled in place with alternate layers of BITUMEN, and surfaced with mineral aggregate, a granule surfaced sheet, or a roof coating.

BUILT UP ROOFING ASPHALT (BURA) OXIDISED BITUMEN: used in the construction of low slope built up roofing (BUR) systems; specification defined by ASTM D312. This material is called Built-Up Roofing ASPHALT (BURA) in North America.

CAS REGISTRY: A large database of chemical substance information in the world containing more than 29 million organic and inorganic substances and 57 million sequences. <http://www.cas.org/>

CAS REGISTRY NUMBER: A CAS Registry Number is assigned to a substance when it enters the CAS REGISTRY database.

CATALYTIC AIR-BLOWN BITUMENS: OXIDISED BITUMENS produced using catalysts in AIR BLOWING

GLOSSARY

COAL TAR: A dark brown to black, highly aromatic material manufactured during the high-temperature carbonization of bituminous coals which differs from bitumen substantially in composition and physical characteristics. It has previously been used in the roofing and paving industries as an alternative to BITUMEN.

COAL TAR PITCH: A black or dark brown cementitious solid that is obtained as a residue in the partial evaporation or fractional distillation of COAL TAR. Coal Tar Pitch has been used in the past in roofing as an alternative to BITUMEN.

COATING BITUMEN: An AIR BLOWN or OXIDISED or polymer modified bitumen used to manufacture roofing membranes or shingles

COLD ADHESIVE: Bituminous CUTBACK used as a glue for application at ambient temperature of polymer modified bitumen membranes

COLD-APPLIED ROOFING BITUMEN: Bitumen roofing products that are applied at ambient temperatures at the work place without any heating (e.g. peel and stick bitumen membrane or membranes applied with the use of a cold adhesive)

COLLOID MILLS: High-speed shearing devices in which hot bitumen can be dispersed using a surfactant in an aqueous solution to produce a BITUMEN EMULSION

COLOURED MINERAL GRANULES: Natural or factory coloured minerals used as light surface protection for bitumen membranes or bitumen shingles.

CRACKING-RESIDUE BITUMENS [THERMAL BITUMENS]: Archaic term, no longer in use

CRUDE OIL: See CRUDE PETROLEUM.

CRUDE PETROLEUM: A naturally-occurring mixture, consisting predominantly of hydrocarbons but also containing sulphur, nitrogen or oxygen derivatives of hydrocarbons, which can be removed from the earth in a liquid state

CUTBACK BITUMENS (PETROLEUM): Bitumen whose viscosity has been reduced by the addition of a CUTBACK SOLVENT derived from petroleum.

CUTBACK SOLVENT (PETROLEUM): Relatively volatile petroleum solvent used in the manufacture of CUTBACK BITUMEN. Typically white spirit (Stoddard Solvent) and kerosine are the petroleum derived solvents employed.

CYCLICS (NAPHTHENE AROMATICS): Compounds with aromatic and naphthenic nuclei with side chain constituents. They are viscous liquids and represent the major proportion of the dispersion medium for the ASPHALTENES and adsorbed resins in bitumen. They constitute 30–60% by mass of the total bitumen,

DRUM-MIXER: An ASPHALT mixing device in which mixtures of MINERAL AGGREGATE and bitumen are heated and combined continuously in a rotating drum.

DYNAMIC SHEAR RHEOMETER: A testing device used to determine the stiffness of bitumens over a range of temperatures and test frequencies. Typically a standard amount of bitumen (25 mm in diameter by 1 mm in thickness) tested between two flat plates (25 mm in diameter). An oscillatory stress or strain of known value is applied to the bitumen sample and the resultant strain or stress is measured. From these data the stiffness of the bitumen is calculated. The stiffness results are part of the specification within the PERFORMANCE GRADED system of specifications.

DURABILITY TESTING: See WEATHERING TEST

EINECS: European Inventory of Existing Commercial chemical Substances; analogous to the CAS system by which chemical substances were registered under the EU Existing Substances Regulation.

ELASTOMER: A polymeric substance (natural or synthetic) which when stretched to a length that is less than its point of rupture and released will recovery substantially to its originally length. Examples are vulcanised natural rubber, styrene butadiene latex rubber, styrene butadiene styrene block copolymer.

EMULSIFIED ASPHALTS: See BITUMEN EMULSIONS.

EQUIVISCIOUS TEMPERATURE (EVT): The temperature at which BITUMEN has a viscosity that is optimum for application in BUILT UP ROOFING (BUR) systems. For mop application the optimum apparent viscosity is 125 centipoise (cP), for mechanical application it is 75cP.

FILLER (Paving): Fine mineral matter employed to give body to a bituminous binder or to fill the voids of sand.

FILLER (Roofing): Fine mineral matter, typically limestone, or slate dust mixed with BITUMEN prior to being applied as a coating in the manufacture of ROOFING SHINGLES and other roofing products.

GLOSSARY

FLASHPOINT: The temperature at which a combustible vapour forms above the surface of BITUMEN in a specific test method. Methods used for ROOFING BITUMEN products are EN ISO 2592 or ASTM D92 for Open Cup Flashpoint and EN ISO 2719 or ASTM D93 for Closed Cup Flashpoint.

FLEXIBLE PAVEMENTS: Road surfacings made from layers of ASPHALT mixes

FLUXED BITUMEN (PETROLEUM): A bitumen whose viscosity has been reduced by the addition of a flux oil derived from petroleum. Note: Typically gas oils of various distillation ranges are employed as the flux oil. FLUXED BITUMEN differs from CUTBACK BITUMENS which also are reduced viscosity BITUMENS in that the flux oils have negligible volatility at ambient temperatures compared to the petroleum solvents used to produce CUTBACK BITUMENS

FLUX: This term has different meanings in different regions. e.g.: North America; also referred to as ROOFING FLUX. A term of art referring to a raw material from which OXIDISED BITUMEN is made. Typically soft bitumens [less than 50 Pa.s @ 60°C (140°F)] are used, although bitumens of higher viscosity can be included within the definition of FLUX. Europe; FLUX refers to FLUX or FLUX OIL; a relatively involatile fluid (oil) used in the manufacture of fluxed bitumen.

FLUX OILS (PETROLEUM): This term has different meanings in different regions. e.g.: North America; High flashpoint hydrocarbon oils (generally paraffinic) added to a ROOFING FLUX prior to oxidising. The purpose of a FLUX OIL is to enable manufacture of OXIDISED BITUMEN with higher penetration values at a given softening point than would be possible without incorporation of the FLUX OIL. Europe; FLUX refers to FLUX or FLUX OIL; a relatively involatile fluid (oil) used in the manufacture of fluxed bitumen, it also refers to the diluent used in the manufacture of OXIDISED BITUMEN.

FOREMAN: Supervises a crew or a particular operation in the placement and compaction process of asphalt.

FUME SUPPRESSING BUR BITUMENS: Proprietary BUR BITUMEN products which contain small amounts of polymer (added during manufacture or at the jobsite) that forms a layer on the surface of the heated BITUMEN, lowering the rate of fume generation. Also known as Low Fuming BITUMENS.

GAS OIL: A liquid petroleum distillate with a viscosity and boiling-range between those of Kerosine and lubricating oil.

GILSONITE: A natural, resinous hydrocarbon found in the Uintah Basin in north eastern Utah, USA.

GLASS MAT OR FELT: A nonwoven mat made with short glass fibers adhered together with a resin and suitable for coating and impregnation with BITUMEN for roofing products.

HARD BITUMEN: A bitumen possessing low penetration value and high softening-point. These are used in the manufacture of high modulus ASPHALT MIXTURES

HOT-APPLIED ROOFING: Application of roofing membranes with hot BONDING BITUMEN as a glue by mopping, pouring, or with mechanical spreaders (pour & roll technique). This is also called HOT BONDING ROOFING

HOT BONDING ROOFING: See HOT APPLIED ROOFING

HOT MIX ASPHALT: A mixture of bitumen and mineral materials used as a paving material that is typically produced at temperatures in the range of 140-160°C (280-320°F). In Europe, the term is synonymous with ASPHALT.

HOT WELDING ROOFING: See TORCHING

Kerosine (Kerosene): A petroleum distillate consisting of hydrocarbons with carbon numbers predominantly in the range of C9 through C16 and boiling in the range of 150–290°C (300–550°F)

LABORERS: Sometimes perform raker tasks and may be on site to perform miscellaneous tasks.

LAKE ASPHALT: Most common form of NATURAL ASPHALT, occurring in Trinidad

LOSS ON HEATING: A common industrial BITUMEN test which measures the weight loss after exposing a small BITUMEN sample to 163°C (325°F) for 5 hours. See ASTM D6.

LOW-SLOPE ROOFING: Roofing products designed for a roof slope of less than or equal to 14 degrees.

MALTENES: Relatively low molecular weight oily fraction of bitumen. The maltenes are believed to dissolve, or disperse the ASPHALTENES in the colloidal structure of bitumen. They are the n-heptane soluble fraction of bitumen.

GLOSSARY

MASTIC ASPHALT: Mastic asphalt (MA) is a voidless asphalt mixture with bitumen as a binder in which the volume of the filler and binder exceeds the volume of remaining voids (see EN13108-6). Typically placed at temperatures in the range of 230-280°C (450-536°F).

MEMBRANE: A factory made flexible layer of bitumen with internal or external incorporation of one or more carriers, supplied in roll form ready for use

MINERAL AGGREGATE: A combination of stone fractions and FILLER

MODIFIED BITUMENS: Bituminous binder whose rheological properties have been modified during manufacture by the use of one or more chemical agents.

MOPPER: A worker who spreads hot bitumen on a roof with a mop

NATURAL ASPHALT: Naturally-occurring mixture of bitumens and mineral matter formed by oil seepages in the earth's crust. Natural asphalts include Trinidad Lake, Rock, Gilsonite, Selenice and others.

OXIDISED BITUMEN. (OXIDIZED BITUMEN): Bitumen whose rheological properties have been substantially modified by reaction with air at elevated temperatures. This material is also sometimes referred to as "blown bitumen" and, in the USA, AIR-BLOWN ASPHALT.

OXIDISED BITUMEN MEMBRANE: A ROOFING BITUMEN product typically made by coating a glass fibre or polyester mat with a mixture of OXIDISED BITUMEN and mineral filler, and then packaging the finished product in rolls. In North America these products may be made with a mineral granule surface and are called "ROLL ROOFING".

OXIDISER: See BLOWING STILL.

PAH, PAC: Polycyclic Aromatic Hydrocarbons is the collective name for a large group of several hundred chemicals that have a characteristic structure of two or more fused aromatic rings. They are a class of organic compounds and also a sub-group of the larger family of chemicals - Polycyclic Aromatic Compounds (PAC).

PAVER OPERATORS (PAVERS): Person stationed on top of the paving machine (placement machine) to drive it as it receives asphalt from delivery trucks and distributes it on the road prior to compaction by rolling.

PAVING BITUMEN/ASPHALT: A bitumen used to coat mineral aggregate, mainly used in the construction and maintenance of paved surfaces and hydraulic works.

PAVING MACHINE: A machine designed for placement a uniform asphalt mat onto a road surface prior to roller compaction.

PENETRATION GRADED BITUMENS: Bitumens classified by the depth to which a standard needle will penetrate the bitumen sample under specified test conditions. (See ASTM D5 and/or EN1426 for an explanation of the penetration test).

PENETRATION INDEX: Indication of the thermal susceptibility of a bituminous binder. The penetration index is calculated from the values of PENETRATION and the SOFTENING POINT. It is based on the following hypothesis of Pfeiffer and Van Doormael:

- a) At the temperature of the softening point, the penetration of a bitumen is 800 dmm.
- b) When the logarithm (base 10) of PENETRATION is plotted against temperature, a straight line is obtained, the slope A of which is defined by:

A PENETRATION INDEX of zero is attributed to a bitumen with a PENETRATION at 25°C (77°F) of 200 dmm and a SOFTENING POINT of 40 °C (104°F).

PENETRATION TEST: Specification test to measure the hardness of bitumen under specified conditions. In which the indentation of a bitumen in tenths of a millimetre (dmm) at 25°C (77°F) is measured using a standard needle with a loading of 100 g and 5s duration. Details of the test can be found in ASTM D5 and/or EN 1426 as well as other sources.

PERFORMANCE GRADED BITUMENS: Bitumens classified based on the research results of the Strategic Highway Research Program (SHRP). PERFORMANCE GRADED (PG) specifications are based on the stiffness of the bitumen at the high and low temperature environment in which the bitumen will be expected to perform within pavement. Currently Performance Graded Bitumens are most widely utilised in the United States and Canada.

PETROLEUM PITCH: The residue from the distillation of thermal cracked or steam-cracked residuum and/or catalytic cracked clarified oil with a SOFTENING POINT from 40 °C – 180 °C (104 °F – 356 °F). Composed primarily of a complex combination of three or more membered condensed ring aromatic hydrocarbons.

GLOSSARY

PLASTOMER: A polymer type which exhibits stiffness and strength but does not recover substantially when deformed. Examples of this type of polymer used in bitumens are ethylene vinyl acetate, ethylene methacrylate, polyethylene, and atactic polypropylene

PLY: A layer of felt or sheet in a roof membrane; a four-ply membrane has at least four plies of felt or sheet at any vertical cross section cut through the membrane.

POLYMER MODIFIED BITUMEN/ASPHALT (PMB/A): Modified Bitumen/Asphalt in which the modifier used is one or more organic polymers.

POLYMER MODIFIED BITUMEN MEMBRANE: A factory made flexible layer of STRAIGHT RUN and/or OXIDISED bitumen modified with elastomeric or plastomeric polymers with internal or external incorporation of one or more carriers, supplied in roll form ready for use.

POLYPHOSPHORIC ACID (PPA): CAS No.: 8017-16-1, Molecular Formula: H₆P₄O₁₃. POLYPHOSPHORIC ACID includes long-chain polymerised units of PO₄ units. A key feature in POLYPHOSPHORIC ACID is the absence of free water.

PROPANE-PRECIPIATED ASPHALT (PROPANE BITUMEN): See SOLVENT PRECIPITATION.

PUG-MILL: Mixer used to combine stone materials and bitumen in an asphalt-mixing plant. The mixing is effected by high-speed stirring with paddle blades at elevated temperatures.

RAFFINATE: The part of a liquid, especially an oil, remaining after its more soluble components have been extracted by a solvent.

RAKERMEN: Person who shovels and rakes excess HMA, fill in voids and prepare joints for compaction by rolling to ensure a road surface free from defects. Sometimes referred to as LABORER.

REFINERY: A facility composed of a group of separation and chemical engineering unit processes used for refining crude oil into different oil products.

RESINS (POLAR AROMATICS): Very adhesive fractions of relatively high molecular weight present in the maltenes. They are dispersing agents (referred to as peptisers) for the **ASPHALTENES:** This fraction is separated using solvent precipitation and adsorption chromatography.

ROAD OILS: Term sometimes used for very soft VACUUM RESIDUE or harder BITUMENS that have FLUX OIL added, or CUTBACKS that have been produced using petroleum with a boiling point greater than 225°C (435°F) added to reduce the viscosity. ROAD OILS are generally used to produce ASPHALT paving mixes for use on very low volume roads in moderate to cold climates.

ROCK ASPHALT: Naturally-occurring form of ASPHALT, usually a combination of bitumen and limestone. Found in south-eastern France, Sicily and elsewhere

ROLL ROOFING: See OXIDISED BITUMEN MEMBRANE or POLYMER MODIFIED MEMBRANE.

ROLLER OPERATORS (ROLLERS): Person driving machinery designed to compact the ASPHALT by rolling to finished specifications.

ROLLING THIN FILM OVEN TEST (RTFOT): A common paving BITUMEN test which subjects a thin film of BITUMEN on the inside of a rolling glass jar to 163°C (325°F) for 85 minutes. See ASTM D2872, or EN 12607-1

ROOFER'S FLUX (also called ROOFING FLUX): A low viscosity, high flashpoint, generally paraffinic residue of vacuum distillation of an appropriate petroleum crude oil used as a feedstock in the manufacture of OXIDISED BITUMEN used in roofing applications.

ROOFING BITUMEN/ASPHALT: Bitumen used for manufacture of roofing systems or roofing products, such as; bitumen shingles, BURA, POLYMER MODIFIED membranes, saturated felt underlayment, and roofing adhesives

ROOFING CEMENT: A material made by adding filler and fibres to either a BITUMEN EMULSION or CUTBACK BITUMEN to make an adhesive used for maintenance and in applying flashings on a new roof. Depending on the performance characteristics sought for particular cements, the BITUMEN used in the formulation may be OXIDISED or STRAIGHT-RUN.

ROOFING FELT: A sheet material, impregnated with BITUMEN, generally supplied in rolls and used in roof construction. See BITUMEN ROOFING FELT.

ROOFING KETTLE: A vessel used to heat binders such as OXIDISED BITUMEN for use in the construction of BUILT UP ROOFING and some POLYMER MODIFIED BITUMEN roof systems.

GLOSSARY

ROOFING SHINGLES: A STEEP-SLOPE ROOFING product. BITUMEN roofing shingles are typically made by coating a glass mat with filled COATING BITUMEN and then surfacing with coloured mineral granules.

ROTARY DRUM DRYER: A device in an asphalt-mixing plant used to dry and heat stone materials

SATURANT BITUMEN: BITUMEN that is used to saturate organic felt to make roofing felt or to make organic based shingles. It can be STRAIGHT-RUN or OXIDISED BITUMEN.

SATURATES: Predominantly straight and branched-chain aliphatic hydrocarbons present in bitumens, together with alkyl naphthenes and some alkyl aromatics. This fraction forms 5–20% of the mass of bitumens

SCREED: Leveling device at the rear of a Paving machine.

SCREEDMAN: Person stationed at the rear of the paver, to control the distribution and grade of the ASPHALT mat as the paving machine moves forward.

SELENICE: A NATURAL ASPHALT from Albania

SELF ADHESIVE BITUMEN MEMBRANE: Roofing or waterproofing polymer modified bitumen membrane applied at ambient temperature with the peel and stick method

SEMI-BLOWN BITUMEN: See AIR-RECTIFIED BITUMEN

SKIP-HOIST: A device for transfer of ASPHALT MIXES from a PUG-MILL to storage

SOFT-APPLIED ROOFING: BITUMEN roofing products that are applied by heating the BITUMEN membrane sufficiently with a torch or hot air welder to ensure good adhesion to the substrate.

SOFTENING-POINT: A specification test measuring the temperature, measured in °C, at which material under standardised test conditions attains a specific consistency. (See ASTM D36 and/or EN1427)

SOLVENT EXTRACTS: Aromatic by-products (extracts) obtained from the refining of BASE OILS

SOLVENT PRECIPITATION: The process by which a hard product, PROPANE-PRECIPITATED ASPHALT, is separated from a vacuum residue by solvent precipitation (usually with propane). PROPANE-PRECIPITATED ASPHALT is truly a bitumen by the definitions applied in this monograph. In

the USA, this process is called ‘solvent deasphalting’ and the product, SOLVENT-REFINED ASPHALT.

SOLVENT-REFINED ASPHALT: Term used in the USA for PROPANE-PRECIPITATED ASPHALT, also referred to PDA pitch or PDA asphalt

STEAM-REFINED BITUMENS: VACUUM RESIDUES that have been subjected to STEAM STRIPPING

STEAM STRIPPING: Injection of steam into a residue which aids VACUUM DISTILLATION

STONE MASTIC ASPHALT, STONE MATRIX ASPHALT (SMA): Referred to as STONE MASTIC ASPHALT in Europe or STONE MATRIX ASPHALT in the United States. SMA is a gap-graded asphalt mixture with bitumen as a binder, composed of a coarse crushed aggregate skeleton bound with a mastic mortar (In Europe SMA is specified by EN 13108-5, in the USA it is specified regionally by State Highways Agencies). It is paved at temperatures typically employed for conventional ASPHALT mixtures.

STEEP-SLOPE ROOFING: Roofing products designed for a roof slope of more than 14 degrees.

STRAIGHT-REDUCED BITUMENS: VACUUM RESIDUES used as bitumens. STEAM STRIPPING may have been used in their production. STRAIGHT REDUCED BITUMENS refer to a bitumen produced to a specific target grade without blending with other bitumen grades to achieve the desired result.

STRAIGHT-RUN BITUMENS: Similar to STRAIGHT-REDUCED BITUMENS and STEAM-REFINED BITUMENS

SULPHUR EXTENDED ASPHALT: A hot mixed asphalt in which part of the bituminous binder is replaced by elemental sulphur, typically at levels between 20–40% of the original bitumen content.

SURFACE DRESSING: Process used to seal road surfaces; a thin film of bitumen, CUTBACK BITUMEN or BITUMEN EMULSIONS is spread, covered with a single or double layer of chippings, and then rolled.

SURFACE TREATMENT: May include SURFACE DRESSING and other techniques, such as spraying with minor amounts of BITUMEN EMULSION to bind surfaces together

TEAR OFF: To remove an existing roof system for replacement.

GLOSSARY

TERMINAL: A facility outside a refinery where bitumen is held for intermediate storage prior to delivery to (or collection by) customers.

THERMALLY CRACKED BITUMENS: Also known as Residues (petroleum), thermal cracked, vacuum: Bitumens produced by thermal cracking

TOPPING PLANT: A 'stand alone' distillation plant. Topping plants are usually found in terminals and used to remove distillate materials added to bitumens for transportation purposes.

TORCHING: Application of a roofing membrane with a propane gas flame, used for melting the side of the roofing membrane, without addition of hot bonding bitumen. This is also called HOT WELDING ROOFING

TRINIDAD LAKE ASPHALT: A NATURAL ASPHALT obtained from the La Brea region of Trinidad

UNDERLAYMENT: Factory made flexible sheets of bitumen (OXIDISED or MODIFIED) which are used as underlay to coverings of sloping roofs (e.g. tiles, slates, shingles)

VACUUM DISTILLATION: Distillation of ATMOSPHERIC RESIDUE under vacuum.

VACUUM RESIDUE: Residue obtained by VACUUM DISTILLATION

VISBREAKING: A relatively mild thermal cracking operation mainly used to reduce the viscosity and pour point of vacuum residues for subsequent use in heavy fuel oils. The process converts a proportion of the residue feedstock to distillate product, e.g. Gas oil.

VISCOSITY: Resistance to flow of a substance when a shearing stress is imposed on the substance. For BITUMEN products, test methods include vacuum-capillary, cone and plate, orifice-type and rotational viscometers. Measurements of viscosity at varying temperatures are used by technologists in all industry segments that utilize BITUMEN materials

VISCOSITY-GRADED BITUMEN: BITUMEN which is graded and specified by the viscosity at a standard temperature, which is typically 60 °C (140°F). ASTM D2171 and EN 12596 are the most commonly used viscosity tests.

WARM MIX ASPHALT: Asphalt mixtures produced at lower temperatures as compared to those typically associated with rolled asphalt pavement. Warm-mix asphalts are produced and placed at temperatures typically 10 – 40 °C (50 – 100 °F) lower than conventional rolled asphalt.

WEATHERING TEST: Various accelerated durability tests have been developed for OXIDISED BITUMENs used in roofing applications. The most prevalent is the Xenon Arc Accelerated Weathering test, where thin OXIDISED BITUMEN films are applied to aluminum panels and then subjected to light, heat, and water sprays in several combinations of time and temperature. See ASTM D4798, ASTM D1669, and ASTM D1670.

WHITE SPIRIT: A distillate petroleum product free of rancid or objectionable odours, boiling-range 150-200 °C (300-390 °F); sometimes described as 'Stoddard solvent'

Appendix A

About the Sponsoring Organizations

ARMA: The Asphalt Roofing Manufacturers Association (ARMA) is the trade association representing North American bitumen roofing manufacturing companies and their raw material suppliers. The association includes approximately 85 percent of North American production of bituminous roofing products. ARMA develops information and conducts research and development on bitumen roofing materials and practices; represents the industry in building code, standard product specification and regulatory matters; and serves as a voice for the industry in promoting its products and addressing other matters of common concern.

For further information, consult ARMA's website (<http://www.asphaltroofing.org/>), or contact:

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Asphalt Roofing Manufacturers Association
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BWA: The Bitumen Waterproofing Association (BWA) is an authoritative voice for the bitumen roofing and waterproofing membrane manufacturing industry across Europe. Formerly known as the International Waterproofing Association, BWA's primary mission is to serve as Europe's central source of advice and information on all bitumen membrane roofing and waterproofing matters both to the industry and to its user groups. It plays a leading role in the creation of harmonized European technical standards for the industry and looks after members' interests in all other legislative areas. BWA members represent approximately 96% of the total European bitumen membrane manufacturing market.

For further information, consult BWA's website: (http://www.bwa-europe.com/content/flash_index.asp),

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NRCA: The National Roofing Contractors Association (NRCA) is the voice of professional roofing contractors worldwide. It is an association of roofing, roof deck, and waterproofing contractors; industry-related associate members, including manufacturers, distributors, architects, consultants, engineers, city, state, and government agencies; and international members. NRCA has more than 4,600 members from all 50 states in the U.S. and from 54 countries, and is affiliated with 105 local, state, regional and international roofing contractor associations. NRCA contractor members range in size from companies with less than \$1 million in annual sales volumes (40 percent of the current membership) to large, commercial contractors with annual sales volumes of more than \$20 million. More than half perform both residential and commercial roofing work and more than one-third have been in business for more than a quarter of a century. NRCA represents roofing professionals before the U.S. Congress, the federal government, and other governmental, technical and scientific bodies; develops and sponsors research, educational and technical support programs.

For further information, consult NRCA's website (<http://www.asphaltroofing.org/>),

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Appendix A

RCMA: The Roof Coatings Manufacturers Association (RCMA) is the national trade association representing U.S. manufacturers of cold-applied bituminous and non-bituminous coatings and cements used for roofing and waterproofing, as well as the suppliers of products, equipment, and services to and for the industry. It currently has more than 50 member companies. RCMA's primary missions are to serve as the voice of the roof coatings manufacturing and supply industry, and to advance product technology and ensure an ongoing supply of quality energy-efficient materials to meet the needs of contractors, consumers and the environment.

For further information, consult RCMA's website (<http://www.roofcoatings.org/>),

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Appendix B

North American and European Production of Bitumen Roofing Products in 2006,

Stratified by Application Temperature

As discussed in the body of this paper, application practices, particularly temperatures, are an important factor in determining the potential for bitumen fume exposures during the installation of bitumen roofing materials. Existing compilations of production or sales, however, do not classify bitumen roofing products based on application temperature. To fill this gap Table 1 was created using three data sources.

In compiling Table 1 statistics it was necessary to reconcile different conventions for measuring the units of roofing products. ARMA Shipment Reports use the unit of “squares”, which is 100 square feet of either production or roof coverage. ARMA reports roof coverage squares for shingles and production squares for all other products.

BWA data are reported as square meters of production for all roofing materials. Finally, NRCA market surveys measure sectors of the North American low-slope market in terms of sales dollars. The NRCA data are used to divide larger sectors like modified bitumen membranes into cold, soft and hot application.

In this Appendix the raw data based on these different reporting systems are used to produce a single standardized measure of the size of each sector of the bitumen roofing industry classified according to application method – i.e., in terms of cold, soft and hot application. The standard chosen was square meters of production and the results of these analyses are then used in Figure 1 and Table 1 for easy comparisons across sectors, application methods and geographic areas. The numbers calculated are for the calendar year 2006, the most recent year for which data are available from all sources, and details of all the calculations are presented below. .

A. Europe

Accounting for European production is straightforward because the data [BWA 2007] are expressed as total area (in millions of square meters) of roofing membranes produced:

B. North America

1. Bitumen Shingles

2006 North American production data for bitumen shingles reported by ARMA [2006] are reproduced in the following table:

**European Production of Bitumen Roofing Products in 2006
Stratified by Application Temperature
(in Millions of Square Meters)**

	Cold-Applied	Soft-Applied	Hot-Applied
Shingles	40	0	0
Built Up Roofing	0	0	2
Oxidized Bitumen Membranes and Bitumen Felt Underlayment	14	256	14
Polymer Modified Bitumen Roofing	32	514	64

Source: BWA [2007]

**North American Production of Bitumen Shingles in 2006
(in Squares of Roof Coverage)**

U.S.	149,829,929
Canada	2,745,652
Mexico	<u>9,028</u>
Total	152,584,609

Source: ARMA [2006]

Appendix B

In North American trade nomenclature, a square of roof coverage is the quantity of roofing material that covers 100 square feet of finished roof surface. Shingles are applied to roofs with substantial overlaps necessary to ensure that the materials shed water. To convert shingle production measured in squares of roof coverage to a surface area measure of roof production, it is necessary to incorporate a factor of 2.4 to account for the additional sheet production needed as a result of the overlap, as follows:

$$\begin{aligned} \text{Surface area shingle production} &= \text{Production in squares} * 100 * 2.4 \\ &= 152,584,609 * 100 * 2.4 = 36,620,306,116 \text{ sq ft.} \end{aligned}$$

This result is converted to the metric equivalent as follows:

$$\begin{aligned} \text{Production in Square Meters} &= \text{Production in Square Feet} / (3.28 \text{ f/m})^2 \\ &= 36,620,306,100 \text{ ft}^2 / 10.76 = 3,403,374,174 \text{ m}^2 \\ &\quad \sim \underline{\underline{3,403 \text{ M m}^2}} \end{aligned}$$

Although more sheet is used in the manufacturing plant to make laminated shingles, this analysis does not adjust the shingle production estimates to reflect this factor. Consequently, in the case of laminated shingles, the estimate of squares produced does not include the additional sheet needed for the laminating step in the manufacture of this product. In 2006, laminated shingles accounted for 68.5% of total North American shingle production [ARMA2006].

2. Built Up Roofing

2006 North American production data for BUR sheets reported by ARMA [2006] are reproduced in the following table:

North American Production of Bitumen BUR Sheets in 2006 (in Squares produced)				
	<u>U.S.</u>	<u>Canada</u>	<u>Mexico</u>	<u>Total</u>
Ply Felts	16,577,083	394,000	0	16,971,083
Base Ply	8,900,931	6,323	0	8,907,254
Mineral Cap Sheet	6,173,144	25,944	0	6,199,088
Totals	31,651,158	426,267	0	32,077,425

Source: ARMA [2006]

Squares produced is the unit used for BUR because these products can be installed with varying numbers of plies when constructing a roof and the available sources do not provide a market-wide average number of plies that would be needed to translate squares produced to squares of roof coverage. Thus, the 2006 BUR total, 32,077,425 squares, is equivalent to 3,207,742,500 square feet of BUR sheet production. This measure, in turn, is converted to the metric equivalent as follows:

$$\begin{aligned} \text{Production in Square Meters} &= \text{Production in Square Feet} / (3.28 \text{ f/m})^2 \\ &= 3,207,742,500 \text{ ft}^2 / 10.76 = 298,117,333 \text{ m}^2 \end{aligned}$$

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The ARMA [2006] Shipment Reports do not differentiate between BUR sheet production that is hot-applied and cold-applied. The NRCA [2007a] Market Survey, however, does provide data on the relative frequency of these two BUR application methods, as shown in the following table:

	New Construction	Re-Roofing	Weighted Average
Hot-Applied BUR	15.8%	17.0%	16.6%
Cold-Applied BUR	1.8%	2.8%	2.5%
Totals	17.6%	19.8%	19.1%

Source: NRCA [2007a]

The weighted average values in the third column of the table are based on NRCA [2007a] survey data finding that 31.8% of low-slope roof construction work in 2006 was new construction, while 68.2% was re-roofing. The weighted average shares of the low-slope market presented in the table indicate that bitumen BUR held 19.1% of the low-slope market in 2006, and that 86.9% [16.6% / 19.1%] was hot-applied, while the remaining 13.1% was cold-applied. These relative application rates can be used to derive estimates of the surface area of BUR production that were hot- and cold-applied in 2006 as follows:

$$\text{Cold Applied: } 298,117,333 \text{ m}^2 * 0.131 = 39,053,371 \text{ m}^2$$

$$\sim \underline{\underline{39 \text{ M m}^2}}$$

$$\text{Hot Applied: } 298,117,333 \text{ m}^2 * 0.869 = 259,063,962 \text{ m}^2$$

$$\sim \underline{\underline{259 \text{ M m}^2}}$$

3. Bitumen Felt Underlayment

Market estimates for bitumen felt underlayment are not available from the sources used in this review. However, because underlayments are ancillary products, an estimate of production can be developed from the primary roof systems under which they are used. Specifically, bitumen felt underlayments are primarily used under shingles, and are applied with little overlap. Accordingly, it was assumed that the surface area of underlayment production equals the surface area coverage of bitumen shingles produced. This assumption probably understates underlayment production because it does not consider overlap, and because underlayments are also used with other roofing systems, particularly non-bitumen shingle and tile roofs.

As derived above, the estimate of 2006 roof coverage of bitumen shingles is 152,584,609 squares, which is equivalent to 15,258,460,900 square feet. This result is converted to the metric equivalent as follows:

$$\text{Production in Square Meters} = \text{Production in Square Feet} / (3.28 \text{ ft/m})^2$$

$$= 15,258,460,900 \text{ ft}^2 / 10.76 = 1,418,072,574 \text{ m}^2$$

$$\sim \underline{\underline{1,418 \text{ M m}^2}}$$

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4. Polymer Modified Bitumen Roofing

2006 North American production data for polymer modified bitumen sheets reported by ARMA [2006] are reproduced in the following table. Again the data are presented as squares produced for the same reason as stated for BUR production.

North American Production of Polymer Modified Bitumen Sheets in 2006

	<u>U.S.</u> (Squares)	<u>Canada</u> (Squares)	<u>Mexico</u> (Squares)	<u>Total</u> (Squares)	<u>Total</u> (m ²)*
SBS, Non-Self-Adhered [†]	8,313,906	48,607	1,110	8,363,623	77,728,838
SBS, Self-Adhered [†]	21,846,871	222,269	0	22,069,140	205,103,532
APP	2,924,213	0	0	2,924,213	27,176,701

Source: ARMA [2006]

The ARMA [2006] data do not provide a breakdown of polymer modified bitumen production according to application method. Self-adhered (peel-and-stick) SBS sheets are, by design, cold-applied. Based on consultation with NRCA [2007b], the analysis assumes the following for non-self-adhering sheets:

APP: 75% applied soft; 25% applied cold

SBS: 50% applied hot; 20% applied soft; 30% applied cold

The following table displays the results:

**North American Production of Polymer Modified Bitumen Sheets in 2006,
Stratified by Application Temperature
(in Millions of Square Meters)**

	Total Production	Cold- Applied	Soft- Applied	Hot- Applied
SBS, Non-Self-Adhered	77	23	15	39
SBS, Self-Adhered	205	205	0	0
APP	27	7	20	0
Totals	309	235	35	39

Source: ARMA [2006], NRCA [2007a]

As discussed above, converting squares to square meters requires multiplying the squares by 100 and then dividing that product by 3.282, or 10.76.

Figures in the table include ARMA [2006] shipments of un-surfaced and factory-surfaced sheet of various thicknesses.

The figures for this product, also called peel-and-stick membranes, include factory-surfaced sheets, un-surfaced sheets manufactured to be covered in place on the roof, and un-surfaced made for installation without coverage.

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C. Summary

The following table, which also appears as Table 1 in the main body of this paper and is the basis for Figure 1 in the Executive Summary, summarizes the results of the preceding analyses:

North American and European Production of Bitumen Roofing Products in 2006, Stratified by Application Temperature (in M m ²)						
	Cold-Applied Products		Soft-Applied Products		Hot-Applied Products	
	NA	EU	NA	EU	NA	EU
Shingles	3,403	40	0	0	0	0
Built Up Roofing	39	0	0	0	259	2
Oxidized Bitumen Membranes and Bitumen Felt Underlayment [†]	1,418	14	0	256	0	14
Polymer Modified Bitumen Roofing	<u>235</u>	<u>32</u>	<u>35</u>	<u>514</u>	<u>39</u>	<u>64</u>
Totals	<u>5,095</u>	<u>86</u>	<u>35</u>	<u>770</u>	<u>298</u>	<u>80</u>
Market Shares by Application Temperature	<u>81%</u>		<u>13%</u>		<u>6%</u>	

Appendix C

European and North American Specifications for Bitumen Roofing Products

Bitumen Shingles

- EN 544: Bitumen Shingles with Mineral and/or Synthetic Reinforcements – Product Specification and Test Methods.
- ASTM D225: Standard Specification for Asphalt Shingles (Organic Felt) Surfaced with Mineral Granules.
- ASTM D3462 Standard Specification for Asphalt Shingles Made From Glass Felt and Surfaced with Mineral Granules.
- CSA A123.1-M: Asphalt Shingles Surfaced with Mineral Granules.
- CSA A123.5-M: Asphalt Shingles Made with Glass Felt and Surfaced with Mineral Granules.

Polymer Modified Bitumen Membranes

- EN 13707: Flexible Sheets for Waterproofing. Reinforced Bitumen Sheets for Roof Waterproofing. Definitions and Characteristics.
- EN 13969: Flexible Sheets for Waterproofing. Bitumen Damp Proof Sheets Including Bitumen Basement Tanking Sheets. Definitions and Characteristics.
- EN 14967: Flexible Sheets for Waterproofing. Bitumen Damp Proof Courses. Definitions and Characteristics.
- EN 13970: Flexible Sheets for Waterproofing. Bitumen Water Vapor Control Layers. Definitions and Characteristics.
- ASTM D6162: Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using a Combination of Polyester and Glass Fiber Reinforcements.
- ASTM D6163: Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using Glass Fiber Reinforcements.
- ASTM D6164: Standard Specification for Styrene Butadiene Styrene (SBS) Modified Bituminous Sheet Materials Using Polyester Reinforcements.

- ASTM D6222: Standard Specification for Atactic Polypropylene (APP) Modified Bituminous Sheet Materials Using Polyester Reinforcements.
- ASTM D6223: Standard Specification for Atactic Polypropylene (APP) Modified Bituminous Sheet Materials Using a Combination of Polyester and Glass Fiber Reinforcements.
- ASTM D6298: Standard Specification for Fiberglass Reinforced Styrene-Butadiene-Styrene (SBS) Modified Bituminous Sheet with a Factory Applied Metal Surface

Oxidized Roofing Membranes or Bitumen Underlayment or BUR Felts

- EN 13859: Flexible Sheets for Waterproofing - Definitions and Characteristics of Underlays - Part 1: Underlays for Discontinuous Roofing.
- EN 13707: Flexible Sheets for Waterproofing. Reinforced Bitumen Sheets for Roof Waterproofing. Definitions and Characteristics.
- EN 13969: Flexible Sheets for Waterproofing. Bitumen Damp Proof Sheets Including Bitumen Basement Tanking Sheets. Definitions and Characteristics.
- EN 14967: Flexible Sheets for Waterproofing. Bitumen Damp Proof Courses. Definitions and Characteristics.
- EN 13970: Flexible Sheets for Waterproofing. Bitumen Water Vapor Control Layers. Definitions and Characteristics.
- ASTM D226: Standard Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing.
- ASTM D2178: Standard Specification for Asphalt Glass Felt Used in Roofing And Waterproofing.
- ASTM D2626: Standard specification for asphalt-saturated and coated organic felt base sheet used in roofing.
- ASTM D4601: Standard Specification for Asphalt-Coated Glass Fiber Base Sheet Used in Roofing.
- CSA A123.2 Asphalt Coated Roofing Sheets.
- CSA A123.3 Asphalt Saturated Organic Roofing Felt.
- CSA A123.16 Asphalt-Coated Glass-Base Sheets.

U.S. (ASTM) and Canadian (CSA) specifications both reflect the North American nomenclature, using the term asphalt to denote bitumen.

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- CSA A123.17 Asphalt Glass Felt Used in Roofing and Waterproofing.

Bitumen for Heated Application on Roof

- EN 13304: Bitumen and Bituminous Binders. Framework for Specification of Oxidized Bitumens.
- EN 14023: Bitumen and Bituminous Binders. Framework for Specification of Polymer Modified Bitumens.
- ASTM D312: Standard Specification for Asphalt Used in Roofing.
- ASTM D6152: Standard Specification for SEBS-Modified Mopping Asphalt Used in Roofing.

Cold Applied Bitumen Based Coatings

- ASTM D41: Specification for Asphalt Primer
- ASTM D1187: Specification for Asphalt Base Emulsion for Use As Protective Coatings for Metal
- ASTM D1227: Specification for Emulsified Asphalt Used as a Protective Coating for Roofing
- ASTM D2822: Specification for Asphalt roof Cement
- ASTM D2824: Specification for Aluminum Pigmented Asphalt Roof Coatings
- ASTM D3019: Specification for Lap Cement Used with Asphalt Roll Roofing

- ASTM D4479: Specification for Asphalt Roof Coatings
- ASTM D4586: Specification for Asphalt Roof Cement
- CGSB 37-GP-2M: Asphalt, Emulsified, Mineral Colloid Type, Unfilled, for Dampproofing and Waterproofing, and for Roof Coatings
- CGSB 37-GP-4Ma: Cement, Lap, Cutback Asphalt, Fibrated, for Asphalt Roofing
- CGSB 37-GP-5Ma: Cement, Plastic, Cutback Asphalt
- CGSB 37-GP-6Ma: Asphalt, Cutback, Unfilled, for Dampproofing
- CGSB 37-GP-8Ma: Asphalt, Cutback, Filled for Roof Coating
- CGSB 37-GP-9Ma: Primer, Asphalt, Unfilled, for Asphalt Roofing, Dampproofing and Waterproofing
- CGSB 37-GP-16M: Asphalt, Cutback, Filled, for Dampproofing and Waterproofing
- CGSB 37-GP-28M: Asphalt, Emulsified, Mineral Colloid Type, Fibrated, for Roof Coatings and for Waterproofing
- CGSB 37-GP-29M: Sealing Compound, Rubber-Asphalt
- CGSB 37-GP-42M: Coating, Roof Aluminum Cutback Asphalt

Appendix D

Physical Properties of Roofing Bitumens

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March 18, 2008

Introduction:

This communication describes the physical properties of roofing bitumens that are of interest in describing the products themselves, their use, and the occupational exposure expected when the products are used. Data are referenced from the literature and then some focused data are presented to fill gaps in that literature.

Roofing bitumen has been misused as a synonym for oxidized bitumen for many years. This likely occurred because oxidized bitumen products like bitumen shingles and built up roofing systems dominated the market in the past. However, this use is no longer acceptable since several important roofing products are now made with straight-run bitumen rather than oxidized bitumen. Specifically, in the 1980's, a new roofing system came into prominence that used polymers to modify bitumen which was subsequently made into a membrane for application on the roof. These systems are commonly called modified bitumen membranes and today have a significant share of the low-slope roofing market in North America and a dominant share in Europe. More recently, membranes for underlayment or for exposed application have been developed based on polymer modified bitumen that are rolled membranes with a sticky side that can be directly applied to the roof deck. These are called peel and stick membranes and are also made using straight-run bitumen. Finally many shingle underlayment products and nearly all bituminous adhesives used in shingle manufacture are made using straight-run bitumen. Today it is clear to those in the industry that a significant fraction of roofing bitumen is straight-run and not oxidized bitumen. Therefore, the term roofing bitumen should be used in a way that refers to an even more diverse range of products with widely different properties than is sometimes reported in the literature.

Background:

Two roofing bitumen products are defined by widely accepted specifications. Shingle coating, at least in North America, must comply with ASTM D3462 which requires the bitumen coating ring and ball softening point (ASTM D36) to be between 190 and 230oF (88 to 110oC) and the needle penetration (ASTM D5) at 77oF (25oC) to be greater than or equal to 15 dmm. Built up roofing bitumen, at least in North America, must comply with ASTM D312 which

requires softening point, penetration, ductility, solubility, and flashpoint ranges for its four different grades. The details of these requirements are found in the appropriate ASTM standards.

Most bitumens used for polymer modified products are specified using penetration as a starting point, and then further tests are done by manufacturers to determine both chemical compatibility with the polymers used to modify the product and the ultimate properties of their membranes. The further testing is very specific and usually considered proprietary to the companies manufacturing the products.

Reviews of roofing bitumen properties have been published previously (1-4). Puzinauskas in 1979 (1) focused on Type 3 BUR bitumen and presented data for four products. He tested for all ASTM D312 properties, and in addition tested volatility and the impact of heating on properties. Wilkinson (2) and Greenfeld (3) reviewed shingle coatings in order to develop tests for durability, and in so doing, they each presented data on fifteen different coatings used at that time. Wilkinson tested specific gravity, softening point, needle penetration at three temperatures, flashpoint and weatherability. Greenfeld tested softening point, penetration at three temperatures, specific gravity, ductility, flashpoint and weatherability. Puzinauskas in 1982 (4) presented data on a wide variety of both shingle and BUR oxidized bitumen and tested the same properties he used in his 1979 publication. In all, he tested 35 type 1 BURAs, 32 type 2 BURAs, 44 Type 3 BURAs, 27 Type 4 BURAs, 4 shingle saturants, and 3 shingle coatings.

In addition to describing BUR bitumen, the 1979 study by Puzinauskas also measured emissions from BUR bitumen kettles used to heat the bitumen to the proper application temperature. He grouped the four bitumens he studied into two that were of "low volatility" and two that were of "high volatility". The determination of volatility was made by comparing Cleveland Open Cup Flashpoint results (low values were equated to high volatility) and loss on heating results (high values were equated to high volatility). The use of these tests by Puzinauskas to characterize volatility is not surprising: The ASTM test methods for loss on heating tests state directly that they measure volatility of the bitumen. The flashpoint test measures the temperature needed to volatilize enough bitumen to reach the lower explosive level in the air space above the flash cup. Looking at emissions from the roofing kettles, Puzinauskas concluded that the gaseous, vapor, and mist or aerosol (which he called total particulate or benzene soluble fraction) components of the bitumen fume released from the kettle were all higher with

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the higher volatility bitumen and lower with the lower volatility bitumen. Or, taking it back to measured properties, Puzinauskas found that low flashpoint and high loss on heating bitumens result in more bitumen fume emission when used in built up roofing kettles than do high flashpoint and low loss on heating bitumens.

These previous reviews are valuable for the breadth of data presented in them, and in the case of the 1979 Puzinauskas study, the linkage that was made of emissions during hot application with volatility tests. The reviews, however, only look at oxidized roofing bitumens and have not adequately surveyed the straight-run bitumen used for roofing, nor have they attempted to compare the change in properties in different roofing bitumens made from a single crude oil source as one goes from straight-run to oxidized bitumen. A test plan was completed to fill this gap and the results of that study are reported below.

Objectives and Scope:

An additional technical investigation was designed to fill some of the gaps in the published properties of roofing bitumens. Important to this design was Puzinauskas's finding that the volatility of roofing bitumen was an indicator of emissions and potential for worker exposure. Roofer's fluxes from two crude oils commonly used to prepare oxidized roofing bitumen were oxidized to a variety of roofing bitumen products to show how physical properties change with oxidation, and to show how volatility and potential for emissions change with oxidation. Further, base bitumens that can be used for modified bitumen membrane manufacture were selected by blending materials from similar crude streams and testing those roofing bitumens against the same parameters. In this way a clear comparison of roofer's flux properties with oxidized bitumens produced from those roofer's fluxes could be made, and a more general comparison with modified bitumen bases could be made.

Materials and Experimental Methods:

The Venezuelan roofer's flux was a vacuum tower bottom made from Tia Juana Medium crude oil and was normal refinery production drawn from a Venezuelan refinery. It has been a common roofer's flux imported to the east coast of the US for over 25 years. The modified bitumen base used in the Venezuelan comparisons was made by blending in the lab 90% of the same Venezuelan roofer's flux made from Tia Juana Medium crude oil with 10% of a PG 64-22 (by AASHTO M320-04) made from another Venezuelan crude oil. The PG 64-22, indeed all the bitumen blend stocks used in the study,

was a refinery produced vacuum tower bottom. The product produced is a common type of blend for modified bitumen base.

The Saudi roofer's flux was a vacuum tower bottom, graded as an AC-5 (by ASTM D3381), made with Saudi crude oil in an U.S. east coast refinery. The polymer modified base was made by blending in the lab 10% of a PG 64-22 from the same refinery and made using Saudi crude, with 90% of a 180-200 pen material made using Saudi crude at a Canadian refinery. Bitumen made from Saudi crude oils is commonly used in all roofing bitumen applications. The preparation of the samples is summarized in Table 1.

A laboratory scale oxidizer was used to oxidize the roofer's fluxes into the oxidized roofing bitumen products. The lab oxidizers hold 6 pounds of bitumen and have an aspect ratio of 6.6 (3.5 inches inside diameter, 23 inches tall), which is in the range of aspect ratios seen in production at Owens Corning (4.2 to 10). The temperature during oxidation is controlled to between 490 and 500F, which is normal in production oxidizers. The air flow used is 30 scfh, chosen to achieve a reaction time similar to that obtained on full production units when running the same bitumen. The head space in the oxidizer is kept at a pressure of approximately 12 inches water column to mimic the head space pressure in full production units. Owens Corning has decades of experience using laboratory equipment like this to produce lab samples of oxidized bitumen that successfully mimic production output.

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**Table 1
Study Plan**

Comparison Groups	<u>Group A</u> Roofing Bitumens Made from Venezuelan Crude	<u>Group B</u> Roofing Bitumens Made from Saudi Crude
Roofing Bitumens and Manufacturing History	1 <u>Roofer's Flux</u> Vacuum tower bottom from Tia Juana Medium crude oil and drawn from actual production in a Venezuelan refinery	1 <u>Roofer's Flux</u> Vacuum tower bottom from Saudi crude and drawn from actual production in an East Coast U. S. refinery
	2 <u>Shingle Saturant</u> Made from Roofer's Flux A in a laboratory- scale oxidizer	2 <u>Shingle Saturant</u> Made from Roofer's Flux B in a laboratory- scale oxidizer
	3 <u>Shingle Coating</u> Made from Roofer's Flux A in a laboratory- scale oxidizer	3 <u>Type III BUR Bitumen</u> Made from Roofer's Flux B in a laboratory- scale oxidizer
	4 <u>Polymer Modified Bitumen Base</u> A laboratory blend of Roofer's Flux A (90%) and a PG 64-22 straight-run bitumen made from another Venezuelan crude (10%). The blend was made a typical specification of 140 to 170 pen at 25° C.	4 <u>Polymer Modified Bitumen Base</u> A laboratory blend of a PG64-22 straight-run bitumen from the same refinery using Saudi crude (10%), with a 180-200 pen straight- run bitumen made using Saudi crude at a different refinery (90%). The blend was made to a typical specification of 140 to 170 pen at 25° C.
Tests for Physical Properties and ASTM Test Methods Used	Softening Point	ASTM D36
	Penetration at 25°C	ASTM D5
	Viscosity at 149°C	ASTM D4402
	Specific Gravity	ASTM D70
	Loss on Heating at 163°C	ASTM D6
	Rolling Thin Film Oven Test at 163°C	ASTM D2872
	Open Cup Flashpoint	ASTM D92

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All the tests run in this study were run according to ASTM Standard Test Methods as summarized in Table 1. These methods included a series of standard ASTM tests commonly used to characterize the physical properties of bitumens – i.e., tests for softening point, penetration and viscosity. In addition flashpoint and weight loss tests (Loss on Heating and RTFOT) were also conducted because these properties characterize volatility and have been shown by Puzinauskas to correlate to fume emission rates in roofing kettles. As stated above, both in the Puzinauskas study and by their very design, lower loss on heating should indicate a lower tendency to produce fume at equal temperatures, and higher flashpoints should indicate bitumen less prone to emit fumes than those with lower flashpoints. Note that for one of the tests used in this study, the Rolling Thin Film Oven Test (RTFOT ASTM D2872), the constant exposure of a thin film of bitumen rotating on the inside of a glass bottle with air induced into the bottle has the result of increasing the uptake of oxygen by the sample -- which can result in a weight gain if its effect is greater than the volatility of the bitumen. To quote the ASTM D2872 test method on this:

“This test can result in either a mass loss or a mass gain. During the test volatile components evaporate, causing a decrease in mass, while oxygen reacts with the sample, causing an increase in mass. The combined effect determines whether the sample has an overall mass gain or overall mass loss. Samples with a very low percentage of volatile components usually will exhibit a mass gain, while samples with a high percentage of volatile components usually will exhibit a mass loss.”

The Loss on Heating test method (ASTM D6) uses a far smaller surface area in contact with air and does not generally exhibit the weight gain from oxygen uptake. In general the Loss on Heating test is more prevalent with oxidized roofing bitumen and the RTFOT is more prevalent in use with straight-run bitumen.

Results:

Results of the experiments outlined in the previous sections are presented in Tables 2 and 3. The results show the following:

1. Roofing bitumen include bitumen with a very wide variety of physical properties, even when taken from the same or similar crude oil sources.
2. The direct comparison of the two roofer’s fluxes with the oxidized bitumen roofing products made from those roofer’s fluxes shows clearly the substantial change in physical

properties as the oxidation process proceeds. In each case when going from flux to coating the softening point more than doubles, the penetration decreases by an order of magnitude, and the viscosity increases by roughly two orders of magnitude.

3. The same direct comparison can be made on properties that measure volatility.

- a. For each crude oil based bitumen the Loss on Heating test shows large decreases in going from flux to saturant to either coating or Type III BURA – for the Venezuelan crude based roofer’s flux and oxidized bitumens in Table 2 the LOH decreases 71% from flux to saturant, and 84% from flux to coating. Similarly for the Saudi crude the LOH decreases are essentially 95% in going from flux to either saturant or Type III BURA.

- b. For both crudes the behavior of the RTFOT loss on heating test is similar, although calculating percentage reductions is complicated by the tendency for very low volatility bitumen to show a weight gain. For Venezuelan crude the RTFOT shows a reduction in loss on heating of 90% from flux to coating. For the Saudi crude the RTFOT shows a significant weight loss for flux and a weight gain for both saturant and Type III BURA.

- c. For both crudes the oxidized products show an increase in flashpoint compared to the flux.

4. The comparison of the polymer modified base bitumen vs. the flux and oxidized bitumens is, as stated previously, less clear since in this case the crude oils used to make the base are not exactly the same as the roofer’s flux and hence oxidized products. The Venezuelan data is the best comparison since the modified bitumen base was made by blending 90% of the roofer’s flux with 10% of a Venezuelan PG64-22. Some observations given this caveat would be:

- a. For both crudes the standard properties of the polymer modified base are closer to those of flux than those of the oxidized products.

- b. Loss on heating for the polymer modified base is more like the flux than the oxidized products. It is clearly higher than the oxidized products on the LOH test and is clearly positive (weight loss) and not negative (weight gain) on the RTFOT test. These results, combined with flashpoint, would indicate a tendency for volatility more like flux than like oxidized for bitumens from these areas.

Appendix D

Conclusions:

Thus, the data in Tables 2 and 3 illustrate that straight-run and oxidized roofing bitumens have markedly different physical properties and markedly different volatilities. The higher softening point oxidized bitumens tend to have considerably lower volatility than the straight-run bitumens. Since Puzinauskas [1978] has shown that tests for volatility correlate to kettle emissions across the entire definition of bitumen fume (gas, vapor, mist & aerosol) it is reasonable to conclude that the trends in Tables 2 and 3 extend not only to volatility but also to emissions. Thus the conclusion that bitumen designed to be used at higher application temperatures by processing with oxidation will also tend to produce fewer fumes at the same temperature than the straight-run bitumen from which they are made. Or, said another way, the oxidized products will produce the same number of fumes at a higher temperature than the straight-run flux that they are made from, or than other straight-run materials made from similar crude oils, at lower temperatures. This is not surprising when one considers that significant volatile materials are stripped from the bitumen during oxidation and collected in the oxidation fume stream. Corbett (5) reports that condensable oils are present in the fume stream during oxidation and represent 0.17 to 1.7% of the bitumen exposed to oxidation. He also reports that lower flashpoint bitumen lost more condensable oils than higher flashpoint bitumen.

The lower volatility of bitumen that are designed to be applied or used at higher temperatures may explain the small differences in worker exposure seen in industry cross sectional exposure studies (6, 7) in spite of a large difference in application temperature in the industries. Oxidized roofing bitumens have been submitted to a process that decreases the tendency to fume to an extent that they can be heated to these higher temperatures but only emit similar levels of fumes.

Table 2:
Physical Properties of Four Typical Roofing Bitumens
Made from a Commonly Used Venezuelan Crude Source

Tests and Units	ASTM Test Method	Straight-Run Roofing Bitumens		Oxidized Roofing Bitumens	
		Polymer Modified Bitumen Base	Roofer's Flux	Shingle Saturant*	Shingle Coating*
Softening Point (°C)	D36	41	41	54	101
Penetration at 25°C (dmm)	D5	163	219	64	18
Viscosity at 149°C (cps)	D4402	145	143	355	13,000
Loss on Heating at 163°C (%)	D6	0.190	0.098	0.028	0.016
RTFOT at 163°C (%)	D2872	0.1880	0.0418	-0.0554 [†]	0.0043
Flashpoint (Open Cup) (°C)	D92	313	313	324	316

* The Shingle Saturant and Shingle Coating Bitumens were blown from the Roofer's Flux tested in this study.

† Negative numbers indicate a weight gain that can occur in the RTFOT test for samples with low levels of volatiles. As described in ASTM D2872, oxygen reactions can result in a weight gain that exceeds the weight reduction arising from the loss of volatiles during the test.

Table 3:
Physical Properties of Four Typical Roofing Bitumens
Made from a Commonly Used Saudi Crude Source

Tests and Units	ASTM Test Method	Straight-Run Roofing Bitumens		Oxidized Roofing Bitumens	
		Polymer Modified Bitumen Base	Roofer's Flux	Shingle Saturant*	Type III BUR Bitumen*
Softening Point (°C)	D36	42	37	54	85
Penetration at 25°C (dmm)	D5	162	310	53	17
Viscosity at 149°C (cps)	D4402	150	95	313	2,135
Loss on Heating at 163°C (%)	D6	0.084	0.165	0.009	0.010
RTFOT at 163°C (%)	D2872	0.0660	0.2991	-0.0730 [†]	-0.0208 [†]
Flashpoint (Open Cup) (°C)	D92	318	318	335	332

* The Shingle Saturant and Type III BUR Bitumen were blown from the Roofer's Flux tested in this study.

† Negative numbers indicate a weight gain that can occur in the RTFOT test for samples with low levels of volatiles. As described in ASTM D2872, oxygen reactions can result in a weight gain that exceeds the weight reduction arising from the loss of volatiles during the test.

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Editor's Note:

Owens Corning is a global building materials and glass reinforcements company with a major presence in bitumen roofing. Its Trumbull Asphalt division is well known as a processor of bitumen, with 14 manufacturing plants 13 of which oxidize bitumen. Owens Corning sells bitumen roofing shingles, and Trumbull sells bitumen used to make both shingles and low-slope roofing systems, in addition to making the bitumen used in Owens Corning products.

Dr. David C. Trumbore is the R&D director for the Trumbull Asphalt division at Owens Corning. Dr. Trumbore has been with Owens Corning for 29 years and in the technology group with the asphalt business at Owens Corning for 24 years. He has published six scientific peer reviewed papers on bitumen covering safety, environmental emissions, and new product development. Dr. Trumbore also holds 16 bitumen related patents in these areas. Dr. Trumbore has a B.S. degree in Chemical Engineering from Lehigh University and a PhD in Chemical Engineering from the University of Washington.

Appendix E

Recent Trends in the Prevalence and Duration of Occupational Exposures to Asphalt Fumes in Roofing Work

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August 15, 2008

A number of estimates of the size of the population of roofing workers exposed to asphalt fumes, and of the frequency and duration of fume exposures, have been published. NIOSH estimated in the 1980s that 12,000 roofing contractors employed over 116,000 workers exposed to asphalt fumes.[1] In 1990, NRCA[2] cited the 1972-74 National Occupational Hazard Survey (NOHS) [3] estimate of 46,000 roofers exposed to asphalt products, but cautioned that work involving asphalt roofing materials does not in many cases entail exposure to asphalt fumes. In 1991, an economic assessment for the U.S. Department of Labor estimated, based on survey data, that 55,000 workers were involved in asphalt roofing application work, again without distinguishing between hot asphalt jobs that generate fumes and other operations. [4] A more recent (2003) NIOSH publication estimated that 50,000 roofing workers are exposed to asphalt fumes for approximately 40% of their working hours.[5] Some existing evaluations of roofing workers also indicate that job tenures of 20 to 30 years are common in the commercial/industrial sector of the roofing industry, the sector which utilizes hot asphalt in some of its operations, although no published assessment has attempted to quantify the prevalence of such long-term workers in the roofing industry.[5]

There are two difficulties with the published estimates on the prevalence of roofer exposures to asphalt fumes. First, as already suggested, several of them are based on the assumption that working with roofing asphalt products necessarily entails fume exposures. The great majority of roofing operations involving the application, removal or repair of asphalt materials do not involve the heating necessary to generate significant concentrations of asphalt fumes. A reasonable estimate of the size of the exposed population must account for this factor. Second, all of the estimates are dated. Several of the estimates are based on the 1972-74 National Occupational Hazard Survey[3] and the 1981-83 National Occupational Exposure Survey.[6] Even the latest NIOSH estimate, published in 2003, was actually based on 1995-96 data.

The past several decades have seen dramatic changes in the economic profile of roofing contractors and key demographic characteristics of the workforce. These factors call for a re-examination of the size of the roofer population exposed to asphalt fumes, the prevalence of hot asphalt work, and worker longevity in the roofing trade.

1. General Description of the Industry and its Workforce

The roofing industry is overwhelmingly populated by small businesses employing a relatively high-turnover workforce sharing the demographic characteristics of the construction industry at large. Out of the total number of roofing contracting companies, 88 percent have 19 or fewer employees.[8] Small and medium size firms with annual revenues of less than \$10 million account for about 75% of the market.[9] The demographic profile of roofing workers tends to mirror that of construction workers in terms of age, gender, ethnicity, education levels, job-related injuries, the influx of foreign workers and lifestyle factors. Many of these factors affect industry tenure and turnover rates – and, therefore, potential duration of exposures to asphalt fumes – and are discussed in greater depth in Section 3 below. Recent data from the Department of Health and Human Service's Substance Abuse and Mental Health Services Administration (SAMHSA) reveal that construction workers have significantly higher-than-average rates of alcohol and illicit drug use compared to other primary occupational groups. [10] Construction workers have among the highest rates of tobacco use among any major occupational group, and roofers in particular have the highest smoking rate among any occupation or trade, including any other construction trade.[11,12]

Estimating the size of the population of roofers potentially exposed to asphalt fumes is no easy task because the existing governmental and industry data do not directly address the question at hand. According to 2005 Census Bureau estimates,[8] the approximately 19,000 roofing contractors in the U.S. who perform roof installation, removal, repair and maintenance employ around 185,000 workers. Some of these workers, however, are “non-production” employees such as clerical, sales and managerial workers. Bureau of Labor Statistics (BLS) estimates relate specifically to defined occupational categories, thus excluding non-production workers. According to 2007 BLS estimates,[13] 123,180 workers are classified as “roofers” (defined to mean workers

* See the 2003 NIOSH publication (Reference 3), at p. 2, citing unpublished Asphalt Roofing Environmental Council (AREC) comments submitted to NIOSH in 1999 [7]. An unpublished NRCA estimate derived from 1995-96 data was the basis for the AREC estimate.

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who “cover roofs of structures with shingles, slate, asphalt, aluminum, wood, and related materials” – see http://www.bls.gov/soc/soc_s2s1.htm), and 21,250 workers are classified as “roofer helpers” (defined to mean workers who “help roofers by performing duties of lesser skill,” including “using, supplying or holding materials or tools, and cleaning work area and equipment” – see <http://www.bls.gov/oes/current/oes473016.htm>). The total of these two BLS-defined groups, 144,430, is reasonably consistent with the Census Bureau data (see note * below).

BLS estimates that 20% of roofing contractors (about 3,800) are sole proprietors,[14] although much higher estimates have been published in the past. Census Bureau data for 2005[8] suggest that there are perhaps 51,000 contractors are “nonemployers” – sole proprietors or partnerships that have no employees (see <http://www.census.gov/epcd/nonemployer/view/define.html#nonemployer>). Although some of these contractors may not perform roofing work themselves, it is conservatively assumed on the basis of these data that the total population of roofing employees can be estimated to be about 236,000 workers [185,000 + 51,000]. Of these, about 41,000 are “non-production” workers unlikely to be exposed to asphalt fumes or any other occupational agent related to roofing work. In addition, it is unlikely that the estimated 21,000 “Roofer-Helpers” have significant exposures to asphalt fumes because of the nature of their duties as defined by BLS (see above). The remainder – the approximately 174,000 workers engaged in roof construction, repair, maintenance or removal operations – will be called “roofers” in this paper.

The roofing industry can be divided into two primary sectors based on the type of building on which the work is done – (1) steep-slope roofs installed on single family homes, attached townhouses and apartment complexes as well as certain commercial structures such as some shopping centers and office buildings; and (2) low-slope roofs found on commercial, industrial and government buildings as well as high-rise residential buildings, hospitals, and schools. These two market segments are often called the “residential” and “commercial/industrial” sectors, respectively, because these are the types of buildings that are the core business in each sector.

The Census and BLS data do not classify roofing contractors or roofers by market sector (i.e., steep slope versus low slope),

and NRCA does not collect this information. According to the 2002 Economic Census,[9] residential roofing sales account for approximately 42.7% of total annual revenues. In the absence of reliable data on relative worker productivity in these two sectors, this paper assumes that the roofer population mirrors sales. It is estimated on this basis that about 43% of the roughly 174,000 roofing workers engaged in construction operations – i.e., around 75,000, are in the steep-slope residential sector. The remaining 57%, or 99,000, are employed in construction operations in the low-slope commercial/industrial sector.

2. Estimating the Roofer Population Exposed to Asphalt Fumes

Asphalt materials are used extensively in both the residential and commercial/industrial sectors of the U.S. roofing market, but only operations involving the heating of asphalt beyond its melting point are associated with exposures to asphalt fumes. The employment data available from the Census Bureau and BLS do not differentiate among roofing workers according to the types of roofing materials or application practices they typically use. It is nevertheless possible to derive reasonable estimates from the information available.

First, it is unlikely that any of the estimated 75,000 workers in the steep-slope residential sector are exposed to asphalt fumes. The only operations involving asphalt roofing materials in this sector are the installation, removal, repair and maintenance of asphalt shingles and asphalt felt underlayments. None of these operations involve the heating of asphalt or potential exposures to asphalt fumes. Steep-slope residential roofers, therefore, can be excluded from the analysis, leaving the estimated 99,000 workers in the low-slope commercial/industrial sector as the population of interest.

Second, the type of roofing operation impacts on the potential for exposure. The most recent NRCA Market Survey[15] results indicate that, using sales as a measure of worker activity (time worked), the breakdown among the three major types of roofing jobs is the following:

- New Construction: 28%
- Re-Roofing: 60%
- Maintenance & Repair: 12%

“Re-roofing” is a trade term referring to a job involving the

* The Small Business Administration's current criterion defining a “small business” in the roofing contractor industry is \$13 million per year in revenues. See http://www.sba.gov/idc/groups/public/documents/sba_homepage/serv_sstd_tablepdf.pdf.

† According to 2002 Census data [9], non-production employees represented about 22% of total roofing industry employment. Assuming the same proportions, the total production workforce in roofing in 2005 was approximately 144,300, while non-production employees numbered about 40,700.

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removal of a roof from an existing building and its replacement with a new roof. On average, installation operations take up 60% of the hours spent by a roofing crew on re-roofing jobs; the remaining 40% is spent on removal (“tear-off”) activities. As a consequence, roofing work in the aggregate is allocated among its principal activities as follows:

- Installation: 64%
- Removal: 24%
- Maintenance & Repair: 12%

Asphalt roofing materials are not heated in typical removal, maintenance or repair activities. Thus, installation activities representing 64% of total roofing hours are the starting point for estimating the prevalence of roofing work involving exposure to asphalt fumes.

Third, not all installation activities involve potential fume exposure. The use of heated asphalt is generally limited to specific steps in the application of the membrane to the roof substrate – specifically, (1) adhering the membrane to the roof substrate; (2) in the case of multiple ply systems, building the membrane in place by sealing the plies together; and (3) in some systems, adding a protective top coat or using hot asphalt in applying a gravel surface. In addition, hot asphalt is sometimes used to apply rigid insulation prior to application of the membrane. Building the roof assembly also entails numerous other steps that do not involve the use of hot asphalt. Depending on the job and the roof system being installed, these additional steps can include: installing and managing safety equipment; construction or repair of the roof deck; installation of vapor retarders; application of rigid insulation (prior to placement of the roof membrane); putting pavers or ballast on the system for securement; material handling; installation of cants, curbs, nailers, and metal flashings (after placement of the membrane); and in some systems today, installing vegetative or photovoltaic systems. On average, membrane installation activities represent much less than half of the total hours involved in roof installation. However, time spent on membrane installation may approach 50% on some BUR jobs (e.g., those involving three or more plies and the use of hot asphalt to apply insulation and a top coat or surfacing). Accordingly, for the purpose of this analysis 50% is assumed, which means that membrane installation accounts for about 32% of total roofing hours.

Whether or not membrane installation activities create significant concentrations of fumes depends on the membrane and the method used to install it. Most existing estimates of the size of the roofer population exposed to asphalt fumes are based on the low-slope roofing market as it existed more than fifteen years ago.[1-5] This is one of the reasons why previous estimates are no longer reasonably accurate measures of fume exposure potential in the roofing industry.

The industry is in the process of a fundamental transformation that began several decades ago, after the introduction in the late 1970s of single-ply roof systems such as polyvinyl chloride (PVC), thermoplastic olefin (TPO) and various rubber-based systems such as ethylene propylene diene monomer (EPDM). [15,16] Before this period, asphalt built-up roofing (BUR) systems dominated the low-slope roofing market, and it was reasonable to assume that the great majority of low-slope roofing contractors were specializing in BUR work.[16,17] A decade later, even though single-ply systems had achieved a substantial share (50% or so) of the low-slope market, hot-applied BUR systems still held a 45% share,[18] and most roofing contractors had specialized in either BUR systems or other low-slope systems. Thus, it continued to be reasonable to assume that fume exposures were largely concentrated among contractors specializing in hot-applied BUR systems, and that the workers employed by those contractors were subject to fume exposures during a substantial portion of their membrane installation activities (about 32% of total construction hours on average, as developed above). This assumption about the structure of the roofing contractor industry was one of the important underpinnings of the exposure estimates NRCA developed in the mid 1990s and provided to NIOSH.

The structure of the roofing industry has changed substantially since the late 1980s/early 1990s, particularly with the decline of hot applied asphalt BUR systems and the rise of cold- and soft-applied polymer modified bitumen systems. Table 1 presents the most recent NRCA Market Survey data[15] identifying the principal low-slope roofing systems sold today and their shares of the market. The survey asks respondents to report separately sales of new construction and re-roofing jobs. For each of the primary roofing systems, Table 1 presents a weighted average of new construction and re-roofing sales to provide a single measure of current market share.

* Nonemployer data are not available in the Census Bureau statistics for roofing contractors, but they are available for “Foundation, Structure, and Building Exterior (FSBE) Contractors,” a broader category of which roofing is a part. In this broader category, “nonemployers” number 294,524, about 28% of FSBE “employer” contractors. Assuming the same incidence of “nonemployers” in the roofing subsector of this category, the number of roofing “nonemployers” is about 51,200.

† BLS [14] states that sole proprietorships are largely concentrated in the residential work, which appears reasonable considering the much larger capitalization and crew size requirements for low-slope roofing jobs. It is therefore assumed that the estimated 51,200 sole proprietor “nonemployer” contractors operate in the steep-slope sector.

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Table 1 does not identify work involving exposures to asphalt fumes, both because it includes systems that do not involve asphalt materials at all (coal tar BUR, single-ply, polyurethane foam, metal, and “other” systems), and because it includes some asphalt systems that are applied without heating. Table 2 re-configures the data to show directly the potential for fume exposures. It also differentiates between traditional hot-applied asphalt systems (such as asphalt BUR and some SBS polymer modified bitumen systems) and those that are “soft-applied” by using propane torches or hot air welders to heat the surface of the sheet sufficiently to ensure adhesion to the substrate. The NRCA Market Survey does not provide information on the application methods used for polymer modified bitumen systems. NRCA believes, however, that about 75% of APP polymer modified bitumen systems are soft-applied, and that the remaining 25% are applied using cold adhesives or are peel-and-stick products. For SBS systems, the hot / soft / cold breakdown is about 50% / 20% / 30%, respectively. These assumptions are used to derive the estimates in Table 2.

The potential for exposures to asphalt fumes during soft application of polymer modified bitumen systems is considered limited or insignificant based on the nature of these operations, but the available exposure data are inadequate and studies are underway to further investigate this question. Assuming for present purposes that these operations may expose workers to significant fume concentrations, Table 2 indicates that operations involving occupational fume exposures represent about 27% [22.27 + 4.38 = 26.65%] of all low-slope membrane installation operations. Applying this estimate to the time allocation estimates developed above, it is reasonable to conclude that approximately 9% [27% * 32% = 8.6%] of all construction hours devoted to roofing work involve installation of membrane systems that may create asphalt fumes. If the subject is limited to hot asphalt operations (i.e., soft-application jobs using torches or hot air welders are excluded), the operations of interest represent about 7% [22.27% * 32% = 7.1%] of total roofing hours.

The market shift away from hot-applied BUR systems, and to cold-applied polymer modified bitumen and non-asphalt single-ply systems, has done more than alter the numerical

Roofing System	New		Weighted Average
	Construction	Re-Roofing	
Asphalt BUR	16.06%	19.85%	18.64%
Coal Tar BUR	0.39%	0.51%	0.47%
Single Ply (EPDM, PVC, TPO)	51.21%	45.76%	47.49%
Spray Polyurethane Foam	2.04%	3.14%	2.79%
Metal	9.88%	6.33%	7.46%
APP Polymer Modified Bitumen	7.02%	7.59%	7.41%
SBS Polymer Modified Bitumen	11.56%	13.17%	12.66%
Other	1.83%	3.62%	3.05%

Source: 2006-07 NRCA Market Survey.^[15] The weighted average is derived from the survey findings that, of sales not involving maintenance and repair, new construction and re-roofing represent 31.8% & 68.2%, respectively.

Roofing System	Hot-Applied	Soft-Applied	Cold-Applied or Non-Asphalt Materials
Asphalt BUR	15.94%	-	2.71%
Coal Tar BUR	-	-	0.47%
Single Ply (EPDM, PVC, TPO)	-	-	47.49%
Spray Polyurethane Foam	-	-	2.79%
Metal	-	-	7.46%
APP Polymer Modified Bitumen	-	1.85%	5.56%
SBS Polymer Modified Bitumen	6.33%	2.53%	3.80%
Other	-	-	3.05%
TOTALS	22.27%	4.38%	73.33%

Source: 2006-07 NRCA Market Survey.^[12]

market shares held by the competing low-slope systems. Because the capital requirements for the newer systems are considerably lower than for BUR, barriers to entry into the low-slope market have fallen. This has opened the door both to entirely new entrants into the market and to diversification by contractors that previously specialized exclusively in BUR systems. Thus, in contrast to the state of the industry twenty years ago, it is no longer the case that hot-applied asphalt work is concentrated in a subgroup of contractors specializing exclusively in such operations.

The available information on potential exposures to asphalt fumes in roofing work can be summarized as follows:

- Excluding white collar workers and roofer-helpers, there are about 174,000 workers engaged in roof construction, repair, maintenance or removal operations; of these, about

* New construction (28% of roofing hours) plus 60% of Re-Roofing (60% of roofing hours) = 28% + 36% = 64%.

† 40% of Re-Roofing (60% of roofing hours) = 40% * 60% = 24%.

* See page 1 above.

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99,000 roofers work in the low-slope sector of the market, where hot-applied asphalt systems are used.

- In the aggregate, about 7% of total low-slope roofing hours are spent on hot asphalt operations involving potentially significant exposures to asphalt fumes.
- Roofers who work on jobs involving hot-applied asphalt roofing products represent a relatively small percentage of the population of low-slope roofers, but because of the strong trend toward diversification in this sector of the industry, it is no longer reasonable to assume that exposure-related work hours are concentrated among a subpopulation of roofers who specialize exclusively in hot asphalt work.

3. Estimating Typical Duration of Exposures to Asphalt Fumes

Employer and employee turnover rates in the construction industry have historically been high and remain so today. Median job tenure in construction is about three years, about 25% below the national average and less than half of the tenures seen in the more stable industrial sectors of the economy.[19] As the BLS[14] has observed, turnover among roofers is even higher than in most construction trades. BLS attributes this to the “hot, strenuous, dirty” nature of roofing work and the significant safety and health hazards it entails – factors which, BLS observes, cause many roofers to switch to jobs in other construction trades. The greatest risks are injuries or deaths from slips or falls, and from burns on hot asphalt jobs. Heat-related illnesses are another serious concern in the summer months. As a result of these circumstances, “a significant number of workers treat roofing as a temporary job until they find other work.”[14]

Despite generally high turnover rates, NIOSH has noted in the past that because of the specialized equipment and expertise needed for hot asphalt roofing work, the commercial/industrial sector includes larger firms with relatively higher commercial longevity and relatively lower rates of worker turnover.[5] NIOSH observed in this connection that “it is common to find workers with 20 to 30 years of experience in the industry.” Because of the specialization that characterized the roofing contractor industry in the past, NIOSH assumed that such longer-term workers were largely concentrated in the subgroup of low-slope contractors exclusively doing hot asphalt work. Previous industrial hygiene studies[20] and employee demographic surveys[21] have yielded additional indications that some roofers have had longer careers in the

trade despite the high turnover rates characteristic of the industry as a whole.

NRCA is unaware of any data permitting a quantitative estimate of how many workers experience tenures in the roofing trade of 10, 20 or more years. There are strong indications, however, that the recent structural supply and demand changes in the roofing industry, coupled with a significant demographic shift in its workforce, will likely reduce the prevalence of long tenures in the trade.

First, as noted above, the rapid growth of single-ply and cold- and soft-applied polymer modified bitumen systems has lowered barriers to entry both for contractors, who face less demanding requirements for capitalization and technical expertise, and for workers, who require less extensive training to install the newer systems. These trends have substantially reduced the market influence of contractors that specialize in hot-applied systems and weakened the factors that were thought to encourage worker longevity in this sector of the industry. In fact, the indications are that the subgroup of low-slope contractors specializing in hot asphalt work that was present in the market 10 or more years ago has largely become economically extinct.

Second, like the construction industry as a whole the roofing industry has been struggling with a shortage of workers for at least the past 20 years.[21,22] The problem has been exacerbated by a series of factors, including: (i) relatively high turnover rates as noted above; (ii) the increasing rates of departure or retirement of older, experienced workers; and (iii) the relative lack of interest among younger Caucasian workers in the roofing trade as a career choice.[17,18,,22] At the same time, the construction industry has seen in recent years a large influx of foreign workers, especially Hispanic migrants. BLS data indicate that Hispanics comprise almost one-third of the current construction workforce, and this percentage is projected to rise as workforce shortages mount, as they are predicted to do, over the coming decade.[23]

These restructuring forces are even stronger in the roofing industry. A 2006 NRCA survey revealed that 69 percent of its members were unable to acquire field workers quickly enough to enable them to perform their work, and that 46 percent have lost work due to worker shortages. The BLS projects that an additional 70,000 roofers will be needed by 2012 to keep pace with projected demand.[23]

Hispanic workers have significantly lower tenure rates than other demographic groups.[19] Accordingly, the dramatic shift in the demographic structure of the roofing industry

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workforce, coupled with the restructuring of the roofing contractor industry away from specialization and towards greater diversification across the various roofing systems on the market today, are strong indicators that tenure rates in the roofing industry are likely to fall well below national averages. According to BLS data, about 25% of workers across all U.S. industries have 10 or more years of tenure with their current employer; about 9% have 20 or more years of tenure. NRCA is not aware of specific data on tenure rates in the roofing industry (whether for one or multiple employers). The considerations identified above, however, suggest that the prevalence of long-term workers in the roofing trade is likely to be well below the national averages, and is likely to decline in the coming years.

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