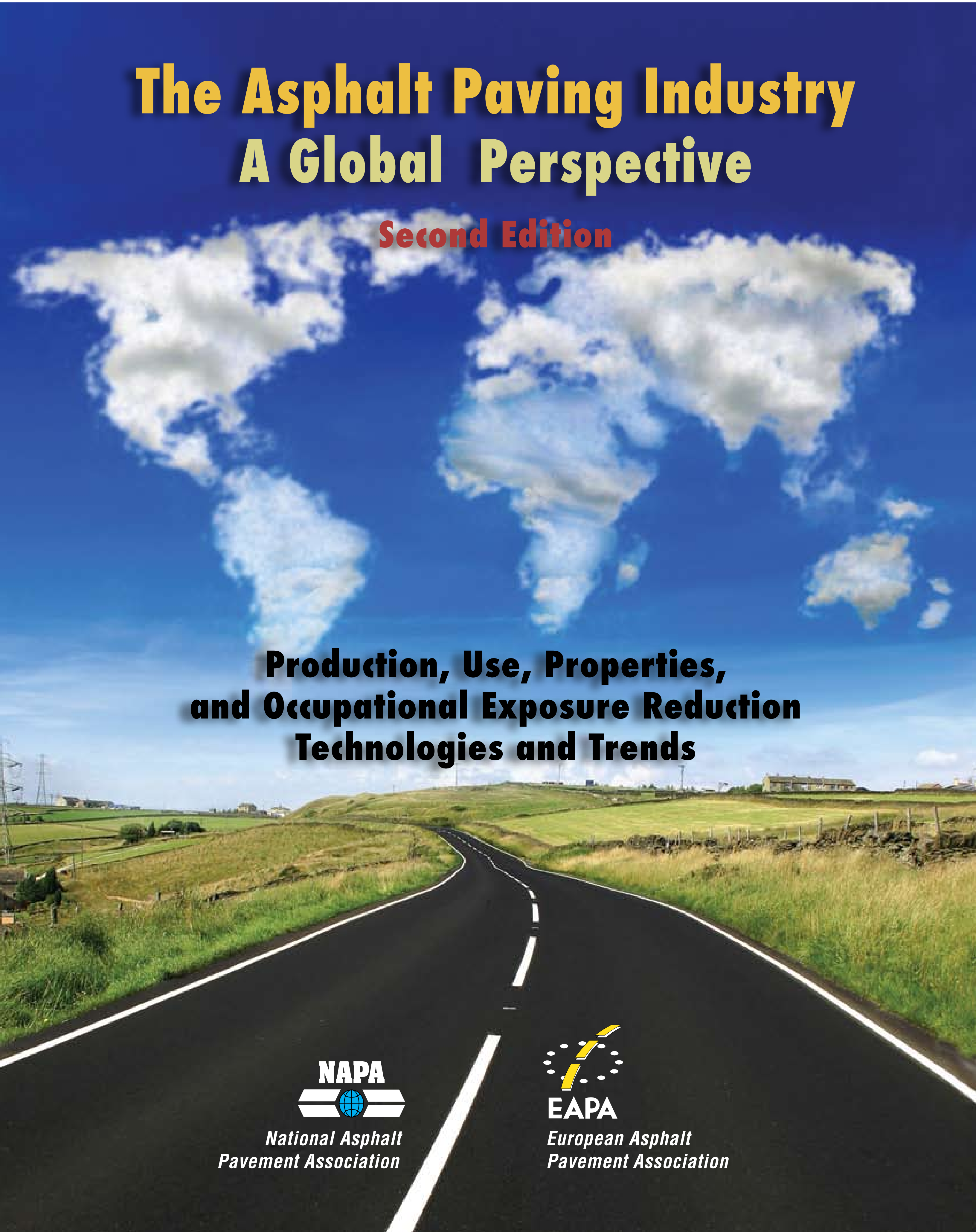
The Asphalt Paving Industry A Global Perspective

Second Edition



Production, Use, Properties, and Occupational Exposure Reduction Technologies and Trends

NAPA
National Asphalt Pavement Association

EAPA
European Asphalt Pavement Association

The Asphalt Paving Industry: A Global Perspective is a joint publication of the European Asphalt Pavement Association (EAPA) and the National Asphalt Pavement Association (NAPA).

EAPA is the European industry association which represents the manufacturers of bituminous mixtures and companies engaged in asphalt road construction and maintenance. Its mission is to promote the good use of asphalt in the creation and maintenance of a sustainable European road network. EAPA represents asphalt producers in 18 countries in Europe.

NAPA is the only trade association that exclusively represents the interests of the U.S. asphalt pavement material producer/contractor on the national level with Congress, government agencies, and other national trade and business organizations. The association, which counts more than 1,100 companies as its members, was founded in 1955.

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Description of the Asphalt Paving Industry

1.1 Introduction

The asphalt paving industry is the industry segment that builds the world's asphalt motorways, highways, streets, airport runways, parking areas, driveways, coastal protection, canal linings, reservoirs, footpaths and cycle paths, and sport and play areas. In order to avoid confusion, the term "asphalt" as used in this document is in accord with European convention and refers to a mixture of bitumen and mineral aggregate designed for specific paving applications. Asphalt plays a vital role in global transportation infrastructure and drives economic growth and social well-being in developed as well as developing countries (Mangum, 2006).

Public investment in highway, street, and bridge construction in Europe totals about €80 billion ($110 billion U.S.) per year. In the U.S., public investment is around €55 billion ($80 billion U.S.) per year. These numbers do not include private-sector investments in streets, parking facilities, or commercial and residential facilities, and other transportation-related structures.

Because of the importance of the infrastructure and the need to ensure the quality and durability of the paved facilities, the industry, in every country, must provide materials and apply production methods which result in an end-product acceptable according to the high standards set by owner agencies.

According to the bitumen industry, 85 percent of all bitumen used world-wide is used in asphalt pavements, 10 percent is used for roofing, and the remaining 5 percent is used in other ways (Asphalt Institute and Eurobitume, 2008).

1.2 Asphalt End Uses

In addition to the construction and maintenance of motorways and trunk roads (major highways), asphalt is also used extensively for rural roads and urban streets, airport runways and taxiways, private roads, parking areas, bridge decks, footways, cycle paths, and sports and play areas.

Europe and North America have by far the most extensive networks of paved roads and highways in the world. In Europe, it is estimated that more than 90 percent of the 5.2 million km (3.2 million mi) of paved roads and highways are surfaced with asphalt. In the U.S., more than 92 percent of the more than 4 million km (2.5 million mi) of roads and highways are surfaced with asphalt. In addition, about 85 percent of airport runways and 85 percent of parking areas in the U.S. are surfaced with asphalt (Mangum, 2006). Canada has about 415,000 km (258,000 mi) of paved roads, and Mexico has about 178,000 km (110,000 mi). In Canada about 90 percent of roads are surfaced with asphalt, as are about 96 percent in Mexico.

There are about 344,000 km (176,000 mi) of roads in Central and South America; about 64,000 km (77,000 mi) in Australia and New Zealand combined; about 1.5 million km (979,000 mi) in China; and 2.5 million km (1.3 million mi) in the rest of Asia.

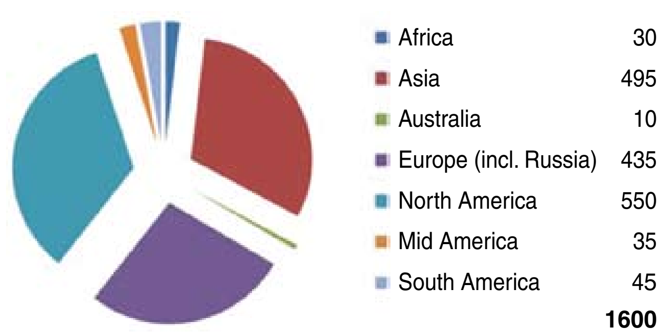
1.3 Asphalt Production Statistics

In 2007, the latest year for which figures are available, about 1.6 trillion metric tonnes of asphalt was produced worldwide. The chart below shows the geographic distribution of production by continent.

1.4 Number of Asphalt Production Sites — Europe and U.S.

Europe has about 4,000 asphalt production sites and produces about 435 million metric tonnes per year. In Europe, 90 percent of companies involved in the production and placement of asphalt can be classified as small and medium sized enterprises.

Figure 1.3
Estimated World Production of Asphalt in 2007
(in million metric tonnes)



(www.eapa.org/default_news.htm)

The U.S. also has roughly 4,000 asphalt production sites and produces about 410 million metric tonnes per year. The paving industry in the U.S. largely grew out of small, family-owned businesses. Today, there is a growing trend for the family-owned businesses in the U.S. to be acquired by larger companies, including multi-national companies operating in both the U.S. and Europe.

Most countries have far fewer plants. For example, Mexico has approximately 400 asphalt plants, South Africa has 60, and New Zealand has 45. An exception is China, where 6,500 small plants collectively produce about 150 million tonnes annually (compared to 4,000 plants producing 435 million tonnes in Europe).

1.5 Number of Workers — Europe and U.S.

In the U.S. and Europe the asphalt paving industry collectively employs about 400,000 workers in the manufacture, transport, and placement of asphalt. Figures for the number of workers in other countries are not readily available.

2

Chemical and Physical Data

2.1 Asphalt Pavement Mixes Typical Composition

Asphalt pavement material typically is composed of about 95 percent mineral aggregates mixed with 5 percent paving bitumen (CAS #8052-42-4), with bitumen functioning as the glue that binds the mineral aggregates in a cohesive mix. Every asphalt pavement mix is designed for a specific pavement application, varying its composition accordingly. The amount of paving bitumen used is typically in the range of 4 to 6 percent by weight of the asphalt mix, depending on the specifications and intended use of the pavement.

2.2 Mineral Aggregates

Aggregates used for asphalt mixtures are typically comprised of crushed rock, gravel, sand, or mineral filler. Occasionally, products from other industries, including foundry sand, blast furnace slag, and glass, may be recycled into asphalt pavement as aggregate. Aggregates are selected and classified according to size and other properties for a specific asphalt mix design and pavement end-use specification.

2.3 Reclaimed Asphalt Pavements

Reclaimed asphalt pavement (RAP) is commonly used in the production of asphalt pavement material to replace virgin mineral aggregates and bitumen. The percentage of RAP included in an asphalt mix depends on several factors. Specifications vary in terms of the amount of RAP allowed and the particular pavement application. Percentages typically vary from 0 to about 30 percent for highway pavements, and may go as high as 60 percent for some applications.

2.4 Properties of Paving Bitumen

2.4-a Physical Properties

Typically, paving bitumen is specified based upon specific physical properties relating to consistency, adhesion properties, viscosity, hardness, or brittleness at a specified temperature. These attributes are important to effective asphalt pavement applications and to the resulting quality and durability of the pavement. Pavement designers select particular paving bitumens that are appropriate to the climate, traffic, and other conditions in which the pavement is used. An important physical attribute is the fact that bitumen becomes softer and more fluid when heated and hardens again when cooled. This attribute allows for the mixing, placement, and compaction of the asphalt mix to form a quality asphalt pavement that can be expediently turned over to traffic.

In Europe and elsewhere, paving bitumen is denoted by the permissible range of penetration value (expressed as a "pen grade," e.g. 40/60 pen grade, 100/150 pen grade), which is indicative of the consistency of the material at a temperature of 25ºC. The softer the bitumen, the higher the penetration. In Europe the bitumen is standardized according to CEN (Central European Normalization) guidelines, differentiating paving grade versus other bitumen types (hard industrial, oxidized, etc.).

In the U.S. and elsewhere, a performance grade ("PG") system has been in use since the mid-1990s. Under this system, both traffic levels and climatic conditions are taken into account. For example, a PG designation of PG 64-22 represents the high and low temperatures (in terms of degrees Centigrade) at which the bitumen would be expected to perform satisfactorily.

2.4-b Chemical Properties

Bitumens are complex chemical mixtures that may be manufactured to yield very different physical and chemical attributes. For example, paving bitumen, CAS #8052-42-4, is most commonly produced through refining of crude oil using atmospheric or vacuum distillation and sometimes mild oxidation (often referred to as air rectification or semi-blowing). Mildly oxidized bitumen, such as is sometimes used to produce semi-blown (air-rectified) paving bitumen, has physical properties similar to those of atmospheric or vacuum-distilled paving bitumen.

Paving bitumens differ from oxidized bitumen or blown bitumen (CAS #64742-93-4). Oxidized bitumen is made by passing air through bitumen at elevated temperatures in order to stiffen it and/or increase the softening point (Asphalt Institute and Eurobitume 2008). In this process, chemical reactions change the chemistry of the bitumen while increasing the material's average molecular weight. Such oxidation is not used to produce paving bitumen.

2.4-c Physical Chemistry

Generation of fume and worker exposures are directly linked to the heating and cooling processes. Production of conventional asphalt pavement material is typically accomplished in the range of 140ºC-160ºC (280ºF-320ºF) (Brown et al. 2000; Brown et al. 2009). The asphalt mix begins to cool when it is transferred from the plant to the trucks transporting it to the pavement site, so placement temperatures are somewhat lower than production temperatures (reductions at this phase of the process being around 5ºC or 10ºF). The quantity and nature of the fume that workers may be exposed to has also been significantly associated with other factors, such as the temperature and conditions of generation (Thayer et al. 1981, Brandt and de Groot 1985, Brandt and Molyneux 1985, Niemeier et al. 1988, Blackburn and Kriech 1990, Lien 1993, Machado et al. 1993, Kitto et al. 1997, Butler et al. 2000, Burstyn et al. 2000, Law et al. 2006, Ruhl et al. 2006, Kriech 2007, Lange et al. 2007, Ruhl et al. 2007). In the past decade, warm-mix asphalt technologies have been developed, allowing production temperatures to be lowered to between 100ºC-140ºC (212ºF-280ºF) (Prowell et al., 2011).

2.4-c Summary of Physical and Chemical Properties

In summary, all bitumens are not the same. Each bitumen is designed and produced for a specific end-use application. Beyond physical characteristics, conditions such as application temperature and other application-related factors should be considered when trying to understand and evaluate exposure potential (see also Chapter 4, Bitumen Fume Exposure and Exposure Reduction).

2.5 Mastic — A Special Pavement Application

Mastic asphalt (referred to as gussasphalt in Germany) is a special product sometimes used for road surfaces in Europe. It is also used in roofing and industrial flooring. A discussion of mastic asphalt can be found in the document *The Mastic Asphalt Industry – A Global Perspective* (2009), and information about roofing can be found in *The Bitumen Roofing Industry – A Global Perspective* (2008).

While mastic is sometimes used for specific paving applications in Europe, it is not used in the U.S. and should not be confused with the predominant and typical asphalt paving applications in both the U.S. and Europe.

Application methods, equipment, and job tasks for mastic asphalt vary from those of conventional asphalt paving. Mastic, as used in road paving, can be spread by hand or with a special paving machine. Harder bitumen grades are used in mastic asphalt, resulting in mixing and placement at 180ºC -250ºC (356ºF-482ºF) — higher than the temperatures for typical asphalt pavements.

2.6 Other Special Applications

Modifications (by fluxing or emulsification) of paving-grade bitumens have specific secondary roles within the asphalt paving industry. Fluxed bitumen involves the mixing of a specific bitumen with lower-viscosity diluents to produce a cutback bitumen which allows application at lower temperatures. It should be noted that cutback bitumen has been largely replaced with the more environmentally friendly bitumen emulsion. Emulsification involves the fine dispersion of bitumen in a solution of water and surfactant. Like cutbacks, emulsified bitumen can be applied at lower temperatures. These products are commonly used to provide a waterproof layer under new pavement surfaces and sometimes to improve bonding between various layers of asphalt pavement; in these cases they are known as “tack coats” or “bond coats.” They are also used in some surface sealing applications such as surface dressing and slurry sealing and to produce a cold-mix patching material that can be stored for longer periods. These special bitumens are typically applied at ambient temperature.

2.7 Coal Tar in Bituminous Pavement Applications

In the past, another type of binder, coal tar (often referred to simply as tar), was used in the paving industry, in varying degrees in Europe, Southern Africa, Australia, and the United States. Because of their similar appearance, little distinction was made between bitumen and tar as a construction material in the past. However, their origin and consequently the chemical composition is quite different. While bitumen is a product of the petroleum refining process, coal tar is a by-product of one of two processes. One process, which results in coke oven tar, is the processing of coal by thermal degradation in a coking plant, used in steel manufacture. The second process yields coal tar as a by-product of making oil from coal. This is sometimes known as the Sasol process, and the product is sometimes called Lurgi tar (Jamieson, 1979).

As a result of the destructive distillation of coal, coal tar contains polycyclic aromatic hydrocarbons (PAHs). It is well recognized that the PAH content—such as that of B(a)P (Benzo[a]Pyrene)—in coal tar is far higher than the PAH content in bitumen.

The economics and availability contributed to different approaches, for example in South Africa tar was relatively abundant and cheaper than bitumen, whereas in the U.S.

tar was more expensive and represented only 1 to 2 percent of the binder market (McGovern et al., 1974).

Europe

Coal tar has been used in all layers of pavement applications in Europe. It was sometimes used at 100 percent, sometimes as a mixture of petroleum-derived bitumen along with tar, and sometimes in a blend with polymers. Some of the products had brand names like Carbo-bitumen (a product of bitumen with tar) that contributed to confusion with regard to the difference between petroleum-derived bitumen and coal tar.

Only after bitumen had replaced coal tar almost completely in Europe during the 1970s and 1980s – due to increasing oil production and declining coke usage and the related economic factors – was the hazard of coal tar to human health and to the environment realized. In Europe, by the early 1990s, the use of coal tar in road paving had been generally discontinued. Unfortunately, many people are still confused by the terminology relating to the historic use of the term “tar.”

Coal tar was used in the following European countries: Belgium (until 1992), Czech Republic (until 1999), Germany (until 1995), Denmark (until 1975), Finland (until 1960s), France (until 1970), Netherlands (until 1991), Norway (until 1960), Sweden (until 1974), Slovakia (until 1980), Turkey (until 1979), and UK (until 1999).

Controls on coal tar use in Europe since about 1990 are intended to prevent the significant presence of coal tar in pavements as a result of recycling.

United States

In contrast, coal tar has not been used much in asphalt pavement applications in the U.S. since World War II. Throughout this time, the economics of petroleum-derived bitumen have been favorable while the sourcing of coal tar was on the decline. Following World War II, there was an increase in traffic volume, travel speeds, and axle loads concurrent with an increased demand for asphalt road construction and maintenance. Production of coal tar for road building applications declined from 675 million litres (178 million gallons) in 1945 to about 2 million litres (540,000 gallons) in 1963, resulting in coal tar being used in less than 3 percent of all bituminous paving materials for road construction in that year. There is evidence of very limited coal tar use as late as 1965 in areas of the country where coal and steel production were prominent. More recent applications for coal tar have been limited to a few non-road applications such as airfields and emulsion application as a pavement sealer for parking lots, driveways, and bridges. State specifications typically prohibit the use of RAP known to contain coal tar (Mundt et al., 2009).

South Africa and Australia

The primary uses of coal tar in South Africa and Australia have been in primers and chip seals.

Some tar mixes have been used in the late 1960s and ’70s in base courses and surface courses including container terminals which are subject to fuel spills, car parks, and bus terminals. In South Africa, estimated use of coal tar in the 1970s was less than 25 percent of all road binders (Jamieson, 1974) and it declined significantly after that time. Road agencies and contractors in South Africa have indicated an intention to discontinue its use (SABITA, 2005).

3

Production, Transport and Placement of Asphalt Mixes

3.1 Description — The Asphalt Mixing Plant

3.1.1 Process Control Mandated by Quality Specifications and Environmental Protection

Today's asphalt plant can be characterized as a modern facility belonging to a sophisticated process industry where emissions are low and well-controlled. Typically, it takes only three to five people to run an asphalt mixing plant. In every country, the asphalt industry must comply with stringent regulations and specifications with respect to materials used, process conditions, and pavement specifications. These regulations and specifications are designed to protect the environment as well as to ensure the quality, durability, smoothness, and safety of the roads.

3.1.2 The Asphalt Mixing Process

There are two types of asphalt plants: batch plants and drum plants. In both, the mineral aggregates are dried and heated in a rotating drum. In batch plants, aggregates are stored in hot bins prior to mixing with bitumen in discrete batches before being stored or loaded into trucks. In drum plants, the mixing of the aggregate and the bitumen takes place in the same drum, after which it is stored in a silo before being loaded into trucks for delivery. Today the predominant plant type in the U.S. and New Zealand is the drum-mix plant. Batch plants prevail in Europe, South Africa, and Australia.

The following diagrams (Figures 3.1a, 3.1b) show the batch plant design and the drum-mix plant design. Process sketches and flow diagrams along with process description follow.

Various asphalt mix formulas are used for the various types of pavement materials. These formulas are engineered to meet the needs of the owner of the pavement. In the case of major roads, highways, and airport runways, the owners are typically governmental entities. In the case of parking areas, low-volume roads, and other facilities, many owners are from the private commercial market, but they often use specifications from government agencies.

Bitumen is stored in heated tanks on site between 150°C (302°F) and 180°C (356°F), which enables the viscous liquid to be pumped through insulated pipes to the mixing plant. The mineral aggregates – stone, sand, and gravel – are stored in stockpiles at ambient temperature. In addition to virgin aggregates, most facilities have stockpiles of reclaimed asphalt pavement (RAP). The aggregate stockpiles are neatly sorted by type and size.

Aggregate and reclaimed materials are taken from various stockpiles and loaded into specific bins. Each size of aggregate and reclaimed asphalt material is fed onto conveyor belts in proportions specified by the job mix formula and transported to be dried in a drum.

At a batch plant, the aggregates are dried and heated in a rotating drum, where the aggregates tumble through a stream of hot air. After drying, the aggregates and any fillers are then mixed in batches with the exact proportions of bitumen and possibly RAP in a second machine called a pug mill.

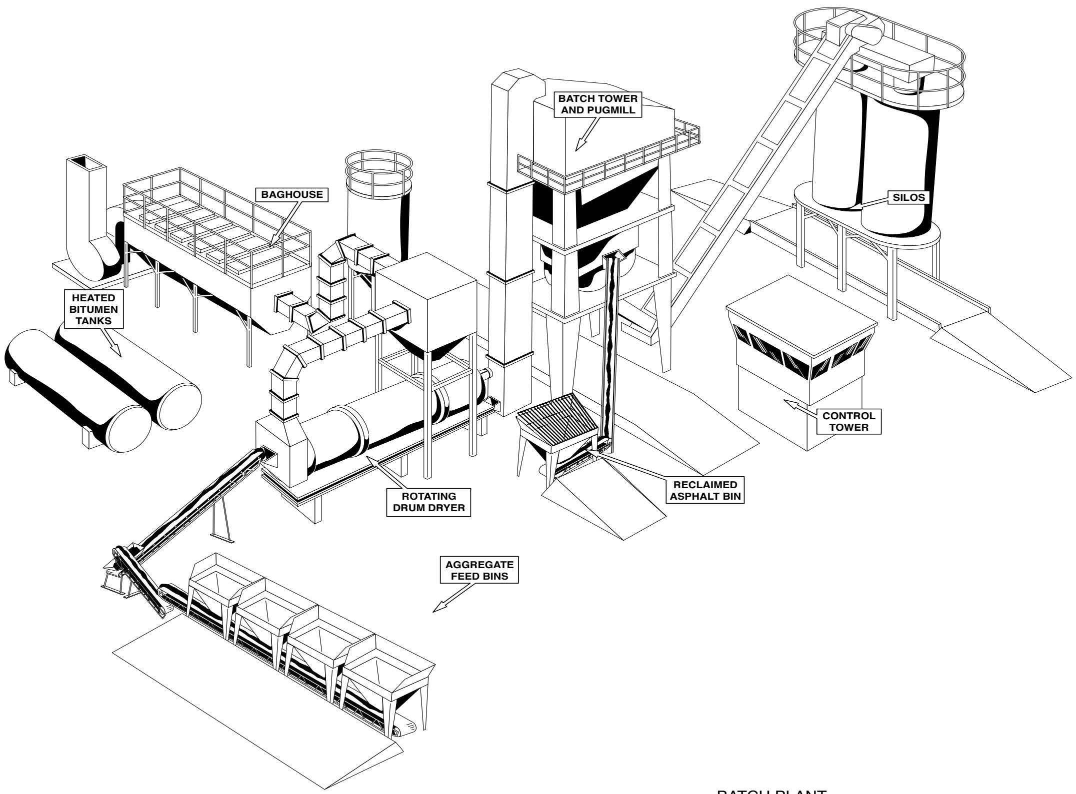
In contrast, at a drum mix plant, the bitumen is added to the dried aggregates and continuously mixed in the same drum used for drying. Here, the RAP and bitumen are added to aggregate far downstream from the source of heat.

Every part of the plant has enclosures and/or control technologies. Most plants are fuelled by natural gas or fuel oil, and state-of-the-art scrubbers keep combustion-related emissions very low.

Dust is controlled in the baghouse, where fines and dust are collected on the outside of filter bags, while clean air passes through the center of the bags. The fines are periodically subjected to bursts of air which force them to the floor of the baghouse, where they are collected for metering back into the paving mix. Clean air is vented out the top.

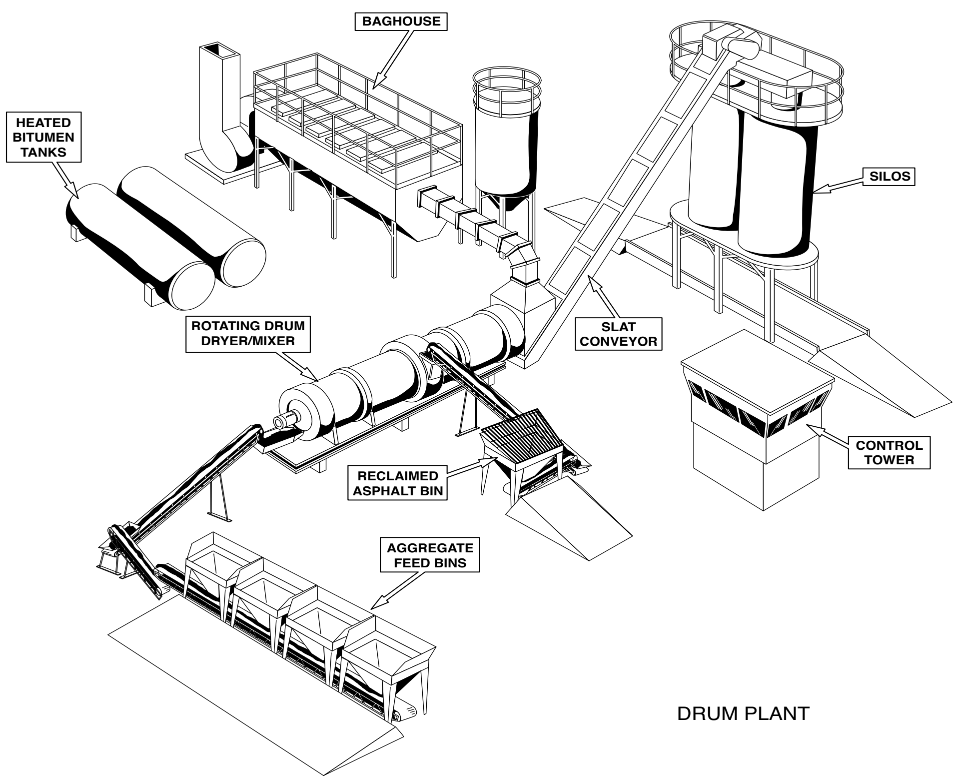
Most plants are on permanent sites, but even portable mixing plants have the advanced environmental controls that are seen on plants on permanent sites.

Figure 3.1a
Batch Plant



BATCH PLANT

Figure 3.1b
Drum Plant



DRUM PLANT

3.2 Description — Truck Loading and Transport to Paving Site

After the aggregates have been dried and thoroughly mixed with the bitumen at the required temperature, the asphalt pavement material may either be temporarily stored in silos on the plant site or discharged directly into a truck for transport to the paving site. The asphalt mix is transported from the plant site to the paving site in trucks. Transport distances vary, but are normally on the order of up to 30-80 km (18-50 mi). The distance of transport is limited, as asphalt must be delivered to the paving site while it is still warm enough to be placed and compacted on the road.

3.3 Description —Asphalt Placement and Roller Compaction

In the beginning of the 20th century, hot asphalt mixtures were spread manually by hand and shovel. Later, asphalt paving machines (mechanical spreaders) were introduced. Beginning in the late 1930s, these paving machines were provided with floating screeds for better levelling and pre-compaction of the asphalt paving mixture The earliest ones were mechanical; they were followed by hydraulic, and later electronic, levelling controls and vibratory screeds.

Today, paving machines incorporate the latest technology. Trucks discharge the hot asphalt mix into a hopper on the paving machine. The material then is conveyed through the paving machine where it is spread across the width of the machine by an auger at the rear of the machine. As the auger distributes the material along the screed, the paver continues to move forward, so that the screed keeps the paving mat level and smooth. The asphalt mix cools throughout this process and must be quickly compacted by a roller to the required pavement density and smoothness by one or more rollers following the paving machine. A paving crew typically consists of one or two paver operators, one or two screed operators, and two or three laborers with rakes and lutes. Each roller has its own operator.

A typical paving machine and roller are illustrated below (Figures 3.3a-3.3b).

Typical Roller

Paving machinery and work practices have constantly evolved since the beginning of the 20th century, as illustrated in (Figures 3.3c).

Figure 3.3b
Roller

Figure 3.3a
Paving Machine

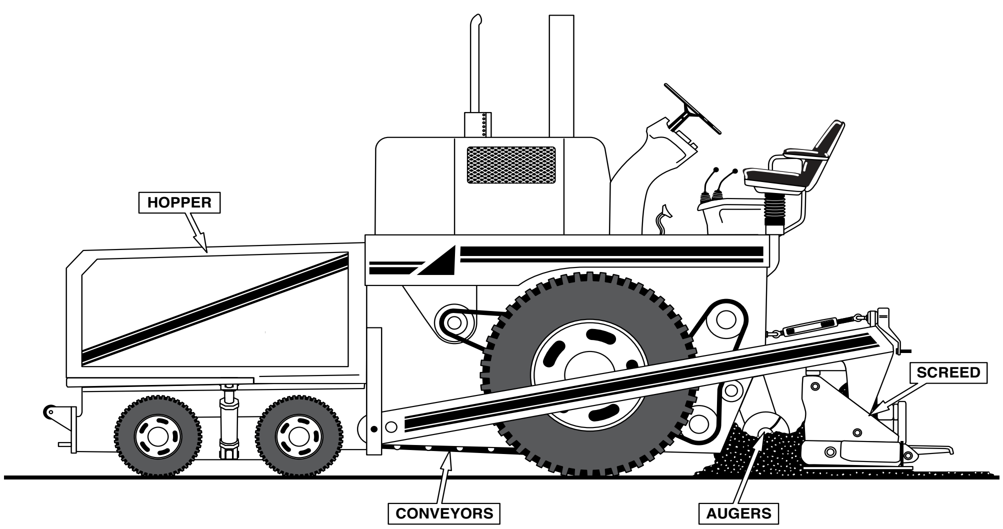


Figure 3.3c
Evolution of Paving Practices

Laying machinery and work practices have constantly evolved since the beginning of the 20th century as illustrated in this pictorial representation.

Manual spreading at the beginning of 20th century

Introduction of machine spreading

1985 paving

2009 paving

4

Bitumen Fume Exposure and Exposure Reduction

4.1 Fume Exposure Potential and Job Tasks

Bitumen fume exposure potential, including the quantity and nature of organic compounds, is directly dependent upon the specific application process conditions including temperature. For 22 U.S. paving bitumens studied in the laboratory, it was found that PAH emissions from bitumen are highly temperature-dependent. It has also been reported that only simple aromatics and very low amounts of 2-3 ring PAHs are emitted at temperatures typically employed for asphalt paving applications (140-160 ºC; 284-320 ºF) (Thayer et al. 1981, Brandt and de Groot 1985, Brandt and Molyneux 1985, Niemeier et al. 1988, Blackburn and Kriech 1990, Lien 1993, Machado et al. 1993, Kitto et al. 1997, Butler et al. 2000, Burstyn et al. 2000, Law et al. 2006, Ruhl et al. 2006, Kriech 2007, Lange et al. 2007, Ruhl et al. 2007).

According to the bitumen refining industry, lowering the bitumen temperature by 11-12.5ºC (20-22ºF) reduces BSM (benzene-soluble matter) fume emissions by a factor of 2 (Asphalt Institute and Eurobitume 2008). As was noted above, production of conventional asphalt pavement material is typically accomplished in the range of 140ºC-160ºC (280ºF-320ºF). In the past decade, warm-mix asphalt technologies have been developed and deployed to allow the production and placement of asphalt pavements at between 100ºC-140ºC (212ºF-280ºF).

Following is a description of job tasks, together with an assessment of the potential for exposure based on both the temperature of the material at different points in the production and placement processes and the proximity of the workers to fume over time.

Figure 4.1.1
Asphalt Plant Operator

4.1.1 Plant Worker Tasks and Bitumen Fume Exposure Potential

Typically, a small crew controls the entire asphalt plant mixing process. The plant operator sits in a climate-controlled operations center. Typically, the other personnel on site are an aggregate loader operator and a maintenance person. These workers tend to be very mobile. Ground-level emissions are sporadic and of short duration, and are typically associated with truck loading. Since the number of workers is small and the persons on site are not in direct contact with a sustained fume environment, it is evident that the possibility for workers to be exposed to bitumen fume at the plant site is limited.

4.1.2 Truck Driver Task and Bitumen Fume Exposure Potential

Truck drivers may encounter fume sporadically during the process of loading a truck at the plant site or unloading the truck at the paving site. Any potential exposure is of short duration and is mediated by the natural factors of wind speed and wind direction, especially that of truck movement. The process of loading or unloading is typically a matter of seconds or minutes during each operation. As a

Figure 4.1.2
Truck Drivers

result, there is little opportunity for sustained exposure relating to the truck-driving task. In addition, the transported asphalt is constantly cooling, thereby diminishing a primary factor relating to the release of fume.

4.1.3 Placement and Compaction Worker Tasks and Potential for Bitumen Fume Exposure

In comparison to plant workers, placement and compaction workers have higher potential for exposure to bitumen fume. These include the paver operators (pavers), screed operator (screedmen), the laborers/rakers, and the roller operator (rollers). Substantial industrial hygiene data has been collected in relation to these tasks. The data presented below substantiate that exposure levels in all tasks are today typically below recommended exposure limits established by the National Institute for Occupational Safety and Health in the U.S. (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH). Following is a description of the tasks as referenced in exposure assessment data.

4.1.4 Placement and Compaction Tasks Defined

A typical paving crew in Europe or the U.S. consists of about five to nine people, as follows:

- **Paver operators (pavers, paving machine operators)** — One or two operators are stationed on top of the placement machine (paver) to drive it as it receives asphalt from delivery trucks and distributes it on the road prior to compaction by rolling. The paver is equipped with a hopper to receive dumped asphalt from truck transport.

  The primary opportunity for fume exposure for these workers would be from the paver hopper or the screed auger.
- **Screed operators (screedmen)** — One or two screed operators are stationed at the rear of the paver to control the distribution and grade of the asphalt mat as the paving machine moves forward. The screed is equipped with a spreading auger to ensure a uniform mat prior to compaction. The primary opportunity for fume exposure for these workers would be from the spreading auger, due to proximity.
- **Rakers** — One or two people shovel and rake excess pavement material, fill in voids, and prepare joints for compaction. Rakers are mobile and move around as needed, but typically are in proximity to the paving machine. Their primary opportunity for fume exposure would be the freshly placed asphalt mat or the spreading auger, depending upon proximity.
- **Laborers** — Laborers sometimes perform the same tasks as rakers and may be on site to perform miscellaneous tasks. This position tends to be more mobile and can be somewhat removed from the primary source of fume surrounding the paving machine.
- **Foremen** — In Europe, a foreman is often in close proximity to the screed while supervising the crew, as reflected in Figure 4,1.3. In the U.S., a foreman is likely to be more mobile.
- **Roller operators (rollers)** — One to three roller operators drive machinery designed to compact the asphalt by rolling it to specifications. Their primary opportunity for fume exposure would be the freshly placed asphalt mat, depending upon their proximity to the placement operation. Operators of the rollers are mobile, operating at varying distances from the primary source of fume surrounding the paving machine.

Generally, the foreman, paver operators, and roller operators do not perform different jobs, while the screed operators, rakers, and laborers may perform a variety of tasks throughout the workday. Crewing schemes may vary from country to country, and according to labor and company work practices.

Figure 4.1.3
Paving Placement Workers

4.2 Bitumen Fume Sampling and Analytical Methods

Factors Affecting Exposure Assessment

Occupational exposure to bitumen fume is measured using a personal monitoring sampler. The type of sampler used and the method by which it is analyzed can lead to substantial differences between measured values (Ekström et al., 2001). When comparing results of personal exposure monitoring surveys it is important to take into account the method used and the metric being evaluated.

Exposure sampling and analytic methods for bitumen fume generally fall into three main categories that measure the following:

- **Particulate matter**
  TPM (Total Particulate Matter): this includes aerosol matter from the bitumen and inorganic material such as dust, rock fines, filler, etc. Because TPM methods collect material from non-bitumen sources the resulting values can suggest artificially high exposure values, especially in dusty environments.
- **Solvent soluble fraction of particulate matter**
  BSM/BSF (Benzene Soluble Matter/Fraction) or CSM/CSF (Cyclohexane Soluble Matter/Fraction): these methods rely on collection of the particulate fraction as described above. However, in order to reduce the confounding exposure to inorganic particulate matter a solvent is used to extract only the organic fraction of the particulates. Such methods more accurately define the exposure to the agent of interest (bitumen fume).

  A sub-set of such methods uses a special monitoring cassette to collect only a specific fraction of the particulate matter, e.g. the respirable, thoracic fractions or inhalable fraction.
- **Organic matter**
  TOM/THC (Total Organic Matter/Total Hydrocarbon): the sum of the organic part of the particulate fraction plus organic vapour phase collected using a back-up absorbent.

  At present, no international standard for the assessment of exposure to bitumen fume exists. As a result, reported values of exposures over time, between studies within the same country, and between the various countries vary significantly and must be considered carefully as to the intended use. Occupational assessment of bitumen fume exposures is susceptible to significant variability in magnitude and constituent from a variety of influencing factors. More research is needed to develop a universally valid, reliable, and easy method of assessing exposures to bitumen fume.

Table 4.2 gives an overview of some important factors influencing the outcome of exposure monitoring.

Sampling and analytical protocols for assessment of exposure to bitumen fume vary significantly from country to country.

There is a difference between bitumen fume and bitumen vapour. When a bitumen is heated a vapour and an aerosol phase are emitted; together, these two phases are collectively known as "fumes from bitumen." The vapour phase is sometimes called semi-volatiles and the aerosol phase is called bitumen fume. It can also be referred to as blue smoke. The bitumen fume has a higher boiling point distribution than the semi-volatile fraction (Brandt et al., 1993).

In an analysis of paving worker exposures in Finland, France, Germany, Norway, the Netherlands and Sweden, no consistent correlation between bitumen fume and bitumen vapour levels could be established (Burstyn et al., 2002).

Table 4.2
Important Factors Influencing the Outcome of Exposure Monitoring

Measurement Task	*Influencing Factor*	*Sub-Factor Influences*
Sampling of bitumen fume	Sampling Device (rate, duration; etc.)	Type of sampler (filter media etc.); sampling characteristics
	Climate	Wind speed/direction; air temperature; humidity
	Ambient Environment	Physical obstacles, tunnels, etc.
	Bitumen Application Being Monitored	Bitumen type and source, application temperature, equipment type and controls; proximity to source
Analysis of bitumen fume	Metric Under Examination, TPM, BSM/BSF, CSM/CSF, Total Vapour, TOM, THC etc.	Dynamic nature of bitumen fumes; aerosol, vapour, and solvent soluble fraction of particulate matter.
	Analytical Method	Extraction solvent, analytical instrumentation, gravimetric, infrared spectroscopy, total absorbance, GC, calibration standard, etc.

In order to better interpret the meaning of different exposure monitoring results, it is important to understand the effect of temperature on fume generation. The Asphalt Institute and Eurobitume have observed, "During handling of bitumen, or bitumen-containing materials at elevated temperatures, small quantities of hydrocarbon emission are given off. In a laboratory study, in the temperature range relevant for paving applications...the Benzene Soluble Fraction emission rate increases by a factor of 2 about every 11-12.5ºC (20-22ºF) temperature increase." (Asphalt Institute and Eurobitume*,* 2008).

4.3 European Exposure Data — Personal Airborne

As was illustrated in section 4.2 above, the reported data in the available national occupational bitumen exposure fume studies vary considerably, particularly due to the various sampling and analytical methods used. In 2000 an extensive review of published literature regarding worker exposure in the road construction industry was published (Burstyn et.al., 2000 AIHJA). The review stated that "the published reports provide some insight into the identity of factors that influence exposure to bitumen among road construction workers: type of work performed, meteorological conditions, temperature of paved asphalt. However, there is a lack of (a) comprehensive and well-designed studies that evaluate determinants of exposure to bitumen in road construction, and (b) standard methods for bitumen sampling and analysis. Information on determinants of other exposures in road construction is either absent or limited. It is concluded that data available through published reports have limited value in assessing historical exposure levels in the road construction industry." Available European asphalt paving worker data are summarized in Appendix II. These data illustrate the variability in sampling and analytic protocol, related exposure metrics, and resulting data country-to-country.

4.4 U.S. Exposure Data — Personal Airborne

Because of the above-referenced disparity in exposure measurement techniques among various countries in Europe, this section is limited to exposure data collected at paving sites within the United States where the exposure method has been reasonably consistent and where the database is large. In the U.S., NIOSH reference method 5042 for Total Particulate and Benzene Soluble Fraction is the typical reference method with reporting on a time weighted average (TWA), eight hour shift basis.

Tables 4.4a, 4.4b, and 4.4c in Appendix III reflect a compilation of U.S. exposure data that was reported in the 2000 NIOSH Health Effects Evaluation of Occupational Exposure to Asphalt in addition to any new U.S. studies conducted and published since the NIOSH 2000 document (Butler et al., 2000).

4.5 Dermal Absorption and Use of Biomarkers — An Emerging Science In the Investigation of Bitumen Fume Exposures

Use of biomarkers to investigate potential bitumen fume exposure, both dermal and inhalation, is an emerging science. Recent scientific efforts have deployed the use of dermal wipe samples and skin patch samples along with specific biomarkers such as urine metabolytes to investigate both inhalation and dermal exposures (Hicks, 1995; McClean et al., 2004 a, b; Zey, 1992 a, b, c; Zhou, 1997). Selected biomarkers of PAH exposure have been employed in such studies along with both laboratory and statistical attempts to quantify the relative influence of dermal versus inhalation pathways on selected biomarkers such as 1-hydroxy pyrene urine metabolite. The use of such tools for dermal exposure assessment is limited today due to difficulty in distinguishing dermal absorption influence on selected biomarkers from that of inhalation influence and due to potential confounding from sources other than bitumen fume exposure. In addition, bitumen fume is a complex mixture (McClean, 2004 a) with poorly understood and potentially complex pharmacokinetics involving the various components of bitumen fume. Given this complexity, much discussion has focused on the selection of appropriate biomarkers for purposes of future research. A comprehensive review of past research efforts is provided by van Rooij et. al. in a report entitled "Review of Skin Permeation Hazards of Bitumen Fumes." While the current body of knowledge relating to the use of biomarkers for assessing dermal absorption is limited in relation to paving worker exposure assessment, significant research is ongoing.

4.6 National Occupational Exposure Limits (OELs)

4.6.1 Europe

The existing occupational exposure limits (OELs) for bitumen fume vary from country to country within Europe, depending mainly on the measurement method; however, even countries adopting the same measurement method may prescribe different limit values. At present neither a binding nor an indicative EU occupational exposure limit value for bitumen fume exists.

To provide an indication of the variety of limit values that exist, a summary of values in some countries is given in Table 4.6.

Table 4.6
Comparison of Occupational Exposure Limits by Country

Bitumen fume – CAS number 8052-42-4

Country	*Limit (mg/m^3)*	*Basis*	*Analytical Metric*
Denmark	1.0	TWA*	Cyclohexane-soluble fraction
Finland	5.0	TWA	Organic dust (also bitumen vapors)
Germany	10.0	TWA	Aerosol and vapor
Ireland	0.5	TWA	Benzene-soluble fraction of aerosol
	10.0	15 min. STEL**	
Italy	0.5	TWA	Benzene-soluble inhalable particulate
Netherlands	5.0	TWA	Set aside as of Jan. 1, 2007
Norway	5.0	TWA	TPM***
Portugal	0.5	TWA	Benzene-soluble inhalable particulate
Spain	0.5	Daily exposure limit	Benzene-soluble inhalable particulate
Sweden	No limit		
Switzerland	10.0	TWA	Total hydrocarbon
UK	5.0	TWA	TPM
	10.0	10 min. STEL	

* Time-weighted average
** Short-term exposure limit
*** Total particulate matter

The countries with low occupational exposure limit values, e.g. Ireland, use a specific organic fraction of the aerosol particulate matter originating from the bitumen to control the emission levels. Countries with higher emission values, e.g. Germany, also take into account additional factors such as vapour.

4.6.2 United States

There is no current federal OSHA (Occupational Safety and Health Administration) existing occupational exposure limit (OEL) for bitumen fume in the U.S. The NIOSH-recommended exposure limit was set in 1977 and remains at 5 mg/m^3, 15 minutes. In 2000, the ACGIH-recommended threshold limit value for bitumen exposures was set at 0.5 mg/m^3 (8-hr TWA) as inhalable fraction, benzene-soluble particulate matter (ACGIH, 2000). The particle size selective sampling device required for measurement of inhalable fraction has been shown to have little effect on the assessment of bitumen fume exposures as the particle size is small (Ekstrom et.al, 2001). As a result, one can make a direct comparison of the ACGIH threshold limit value to traditional U.S. data generated according to NIOSH method 5042 when reported as benzene soluble matter (BSM).

4.7 Exposure Reduction — Europe and U.S.

Recent research reported significant reductions in paving workplace exposure levels since 1960 in Europe (Burstyn et. al. 2003). The discontinuance of coal tar use in Europe combined with best practices and technological advances have had a dramatic effect on paving worker exposures.

Over the past decade or more, the paving industry in the U.S. has intensively engaged in bitumen fume reduction efforts surrounding paving operations (Acott 2007, APEC 2000). Beginning in 1996, the asphalt industry in the U.S. initiated a partnership with NIOSH, labor unions, and FHWA to explore opportunities to minimize fume exposure surrounding paving operations through the application of engineering controls. This effort led to a voluntary agreement with OSHA to install such control systems on all highway-class paving machines manufactured in the U.S. after July 1, 1997.This process included the development of guidelines for the engineering controls (Mead and Mickelson, 1997).

It is estimated that most highway-class pavers currently in use in the U.S. are now equipped with engineering controls. This same government/industry/labor partnership recently conducted a follow-up study to benchmark the use and effectiveness of engineering controls (Michelsen et.al, 2006). Personal monitoring of the paver operator, raker, and screedman was completed along with aerodynamic particle size measurements. NIOSH sampling and analytic protocol 5042 was employed, yielding 437 samples— a combination of total particulate (TP) matter and benzene-soluble fractions (BSF). Results from the study indicated a TP arithmetic mean of 0.36 mg/m^3, 95 percent confidence limits (0.27, 0.69) and BSF arithmetic mean of 0.13 mg/m^3, 95 percent confidence limits (0.07, 0.43). Both TP and BSF means were significantly below NIOSH- and ACGIH-recommended exposure limits of 5mg/m^3 and 0.5 mg/m^3 respectively on a time-weighted average basis.

Application temperature is widely recognized as a very significant parameter in the generation of fume. More recently, warm-mix asphalt has been developed as an innovative method of fume reduction at the source. These technologies allow asphalt to be produced and placed on the road at significantly lower temperatures than conventional asphalt mixes. Lowering the mixing and placement temperature by 10-38ºC (50-100ºF) has numerous other operational and environmental benefits. Most important, warm-mix asphalt has the potential to virtually eliminate fume surrounding paving workers.

Led by an industry/agency/academia partnership, these various technologies are undergoing rigorous laboratory and field performance testing as well as industrial hygiene monitoring in the U.S., Europe, and other parts of the world. U.S. warm-mix asphalt use is on an exponential growth curve (Acott, 2008). The industry and its associations, government agencies, and academic institutions are jointly supporting accelerated research and deployment as well. The mission is to accelerate the implementation of warm-mix technologies by providing technical guidance. In addition, formal mechanisms are in place to coordinate information and education efforts between international audiences. Significant documents on warm mix include *Warm-Mix Asphalt: Best Practices* (Prowell et al., 2011)

Appendix I

Bitumen Industry Terms

%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 OXIDIZED BITUMENS.

AIR-BLOWN ASPHALTS
See OXIDIZED BITUMENS

AIR-BLOWN BITUMENS
BITUMEN products produced by AIR BLOWING. See OXIDIZED 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).

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 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 utilize 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.

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

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 FUME
The gases and vapors emitted from heated BITUMEN, and the aerosols and mists resulting from the condensation of vapors after volatilization from heated BITUMEN.

BITUMEN GRADING TERMINOLOGY
There are currently three main grading systems employed world-wide 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 MACADAM
A type of ASPHALT mix with a high stone content and containing 3–5 percent by weight of bitumen.

BITUMEN PAINT
A specialized 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 OXIDIZER or Bitumen Blowing Unit.) Equipment used to air blow BITUMEN.

BONDING BITUMEN
OXIDIZED 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 fiber) 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)
OXIDIZED 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.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
OXIDIZED BITUMENS produced using catalysts in AIR BLOWING.

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 OXIDIZED 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

COLORED MINERAL GRANULES
Natural- or factory-colored 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 sulfur, 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 kerosene 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 vulcanized natural rubber, styrene butadiene latex rubber, and styrene butadiene styrene block copolymer.

EMULSIFIED ASPHALTS
See BITUMEN EMULSIONS.

EQUIVISCOUS 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 a 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.

FLASHPOINT
The temperature at which a combustible vapor 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 OXIDIZED 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; 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 oxidizing. The purpose of a FLUX OIL is to enable manufacture of OXIDIZED 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; Relatively involatile fluid (oil) used in the manufacture of fluxed bitumen, it also refers to the diluent used in the manufacture of OXIDIZED 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 job site) 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 KEROSENE and lubricating oil.

GILSONITE
A natural, resinous hydrocarbon found in the Uintah Basin in northeastern 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

KEROSENE (KEROSINE)
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 five 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.

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 230280°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.

OXIDIZED BITUMEN (OXIDISED BITUMEN) — CAS #64742-93-4
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.

OXIDIZED BITUMEN MEMBRANE
A ROOFING BITUMEN product typically made by coating a glass fiber or polyester mat with a mixture of OXIDIZED 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.

OXIDIZER
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 CEMENT IN THE U.S.) — CAS #8052-42-4
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 of 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 millimeter (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) in the U.S. 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 utilized 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 40ºC–180ºC (104ºF–356ºF). Composed primarily of a complex combination of three or more membered condensed ring aromatic hydrocarbons.

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 (POLYMER-MODIFIED ASPHALT CEMENT IN THE U.S.) (PMB/A)
Modified Bitumen/Asphalt Cement 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 OXIDIZED 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-PRECIPITATED 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.

RAKER
Person who shovels and rakes excess asphalt, fills in voids, and prepares 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 peptizers) 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 southeastern France, Sicily, and elsewhere.

ROLL ROOFING
See OXIDIZED 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 OXIDIZED 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 fibers 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 OXIDIZED 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 OXIDIZED BITUMEN for use in the construction of BUILT-UP ROOFING and some POLYMER-MODIFIED BITUMEN roof systems.

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 colored 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 OXIDIZED BITUMEN.

SATURATES
Predominantly straight and branched-chain aliphatic hydrocarbons present in BITUMENS, together with alkyl naphthenes and some alkyl aromatics. This fraction forms 5 to 20 percent 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 ºC, at which material under standardized test conditions attains a specific consistency. (See ASTM D36 and/or EN1427).

SOLVENT EXTRACTS
Aromatic byproducts (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, while in the U.S. it is specified regionally by state highway 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 bitumens 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

SULFUR-EXTENDED ASPHALT (SULPHUR-EXTENDED ASPHALT)
A hot-mix asphalt in which part of the bituminous binder is replaced by elemental sulfur, typically at levels between 20-40%m 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.

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 (OXIDIZED 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 in the range of 100º-140ºC (212-280ºF) and are typically 10– 0ºC (50–100ºF) lower than conventional rolled asphalt.

WEATHERING TEST
Various accelerated durability tests have been developed for OXIDIZED BITUMENs used in roofing applications. The most prevalent is the Xenon Arc Accelerated Weathering test, where thin OXIDIZED 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 odors, boiling-range 150-200 °C (300-390 °F); sometimes described as “Stoddard solvent.”

Appendix II

Summary European Exposure Data by Country

Table 1. Personal Airborne Exposure Levels (mg/m^3) Measured at Open European Paving Sites

Exposure Metric	*Job category*	*Number of samples*	*Geometric mean (mg/m^3)*	*Arithmetic mean (mg/m^3)*	*Median (mg/m^3)*	*Reference number*
Total particulate	all	45	*	0.6	*	12
		17	0.58	0.66	*	2
	all except pavers	215	*	0.3-0.7	*	1
	pavers	72	*	1.1	*	1
		20	0.4	0.7	*	7
		5	*	0.58	*	8
		16	0.3	*	*	11
	rakers	13	0.4	0.6	*	7
	screedmen	10	0.5	0.6	*	7
		12	*	0.83	*	8
		32	0.3	*	*	11
	rollers	10	0.2	0.2	*	7
		8	0.4	*	*	11
	others	4	0.3	0.4	*	7
Total vapors plus aerosols	pavers	119	*	*	2.58	10
	screedmen	149	*	*	2.78	10
	rollers	47	*	*	0.98	10
Bitumen fume	all	175	0.03	0.10	*	3a
		83	0.13	0.35	*	3b
	pavers	20	0.15	0.35	*	7
	rakers	13	0.17	0.17	*	7
	screedman	10	0.12	0.19	*	7
	rollers	10	0.04	0.05	*	7
	others	4	0.08	0.10	*	7
Carbon disulfide extractable	all	51	0.28	*	*	9
Chloroform extractable	pavers and screedmen	58 total	*	1.2	*	6
	rollers		*	0.3	*	6
Cyclohexane extractable	pavers	5	*	0.17	*	8
	screedmen	12	*	0.16	*	8
	all	17	*	1		5
		8		0.6	*	12
PAHs (µg/m^3) [a]	pavers	11	*	*	0.62	4
		12	3.20	4.28	*	7
		12	1.8	*	*	11
	rakers	37	*	*	0.64	4
		10	2.69	3.50	*	7
	screedmen	11		*	0.48	4
		10	2.97	3.64	*	7
		29	1.6	*	*	11
	rollers	13	*	*	0.50	4
		10	1.87	2.38	*	7
		7	1.3	*	*	11
	others	4	0.44	1.09	*	7
4-6 ring PAHs (µg/m^3)	pavers	12	0.07	0.18	*	7
	rakers	10	0.18	0.27	*	7
	screedmen	10	0.19	0.26	*	7
	rollers	10	<0.05	0.14	*	7
	others	4	<0.05	<0.05	*	7
SVOCs	pavers	20	1.9	4.2	*	7
	rakers	13	2.6	3.3	*	7
	screedmen	10	1.9	3.1	*	7
	rollers	10	0.8	1.1	*	7
	others	4	0.4	0.6	*	7
Oil mist	pavers	7	0.23	*	*	11
	screedmen	9	0.09	*	*	11

a) See references 4, 7, and 11 for identification of specific PAHs included in these data.

b) Entries with an asterisk (*) indicate that these data were not reported.

c) Exposure Metrics and sampling and analytical methods vary by country

d) Summary statistics from references 1, 8, 9, and 12 are based on analyses in NIOSH 2000

e) Summary statistics from reference 6 are based on analyses in Burstyn et al. 2000.

Table 1 References

No.	*Citation*	*Country*
1	Byrd and Mikkelsen 1979	Denmark
2	Burstyn et al. 2002a	Netherlands
3a	Burstyn et al. 2002b, 1991 data	Norway
3b	Burstyn et al. 2002b, 1992 data	Norway
4	Cirla et al. 2007	Italy
5	Claydon et al. 1984	Netherlands
6	Ekstrom 1990	Sweden
7	Heikkilä et al 2002	Finland
8	Monarca et al. 1987 (summary data from NIOSH 2000)	Italy
9	Norseth, et al. 1991 (summary data from NIOSH 2000)	Norway
10	Rühl et al. 2007	Germany
11	Ulvestad et al. 2007	Norway
12	Virtamo et al. 1979	Finland

Appendix III

Summary United States Exposure Data by Country

The following tables reflect a compilation of U.S. exposure data that was reported in the 2000 NIOSH Health Effects Evaluation of Occupational Exposure to Asphalt (Reference NIOSH Hazard Review Document, Table 4-12) in addition to any new U.S. studies conducted and published since NIOSH 2000 document.

Table 4.4a. Personal Airborne Exposure Levels (mg/m^3) Measured at Open U.S. Paving Sites

Measurement type	*Job category*	*Number of samples*	*Geometric mean (mg/m^3)*	*Arithmetic mean (mg/m^3)*	*Reference number*
Total particulate	pavers	7	.45	*	1
		10	0.17	0.21	3
		2	0.8	*	5
		2	0.85	*	6
		2	0.62	*	7
		2	0.39	*	8
		1	0.0087	*	9
		4	0.34	*	10
		2	0.17	*	11
		44	*	0.34	12
	laborers/rakers	20	0.39	*	1
		7	0.34	0.34	2
		3	0.27	0.35	3
		5	0.33	*	5
		7	0.27	*	6
		8	0.48	*	7
		4	0.077	*	8
		4	0.031	*	9
		4	0.16	*	10
		10	0.22	*	11
		44	*	0.32	12
	screedmen	12	0.72	*	1
		10	0.48	0.54	2
		15	0.24	0.28	3
		2	0.43	*	5
		2	0.31	*	6
		4	0.70	*	7
		8	0.10	*	8
		4	0.078 (A)	*	9
		2	0.22	*	10
		4	0.12	*	11
		44	*	0.36	12
	rollers	13	0.23	*	1
		5	0.30	0.4	2
		1	0.36	0.36	3
		5	0.053	*	5
		4	0.21	*	6
		2	0.18	*	7
		4	0.057	*	8
		6	0.04	*	9
		4	0.055	*	10
		6	0.10	*	11
	other	37	0.37	0.43	2
		15	0.19	0.23	3
Respirable particulates	pavers	7	0.21	*	1
	rakers	20	0.15	*	1
	screedmen	12	0.27	*	1
	rollers	13	0.05	*	1
Benzene solubles	pavers	7	0.11	*	1
		10	0.05	0.08	3
		2	0.59	*	5
		2	0.33	*	7
		4	0.22	*	10
		44	*	0.16	12

Measurement type	Job category	Number of samples	Geometric mean (mg/m³)	Arithmetic mean (mg/m³)	Reference number
	laborers/rakers	20	0.10	*	1
		3	0.11	0.16	3
		5	0.17	*	5
		8	0.13	*	7
		4	0.055	*	10
		44	*	0.08	12
	screedmen	12	0.27	*	1
		2	0.29	*	2
		15	.08	0.13	3
		4	0.19	*	7
		2	0.082	*	10
		44	*	0.15	12
	rollers	13	0.06	*	1
		1	0.07	0.07	3
		5	0.022	*	5
		2	0.014	*	7
		4	0.030	*	10
	other	15	0.07	0.10	3
Total PACs	rakers	24	0.0036	*	4
	screedmen	15	0.0073	*	4
	rollers	11	0.001	*	4
PAC370	pavers	2	0.030	*	5
		2	0.018	*	7
		1	0.0027	*	8
		2	0.0018	*	9
		2	0.060	*	10
	laborers/rakers	5	0.0079	*	5
		8	0.0081	*	7
		3	0.00039	*	9
		2	0.016	*	10
		2	0.011	*	11
		4	0.017	*	7
PAC370	screedmen	2	0.0091	*	5
		4	0.0015	*	8
		4	0.00087	*	9
		2	0.072	*	10
		1	0.0039	*	11
PAC370	rollers	5	0.00018	*	5
		2	0.0014	*	6
		2	0.0011	*	7
		1	0.0011	*	8
		6	0.00007	*	9
		4	0.0053	*	10
	PAC400 pavers	2	0.0043	*	5
		2	0.0024	*	7
		1	0.00043	*	8
		2	0.00027	*	9
		2	0.0085	*	10
	laborers/rakers	5	0.0012	8	5
		8	0.0011	*	7
		3	0.00009	*	9
		2	0.0024	*	10
		2	0.0030	*	11
	screedmen	2	0.0013	*	5
		4	0.0023		7
		4	0.00020	*	8
		4	0.00015	*	9
		2	0.0098	*	10
		1	0.0012	*	11
	rollers	5	0.00004	*	5
		2	0.00025	*	6
		2	0.00015	*	7
		1	0.00017	*	8
		6	0.00001	*	9
		4	0.00067	*	10

Table 4.4a. References

a) Note: All Data from original references 1, 2 and 5 -11 are taken from the summary tables in the NIOSH Hazard Review (2000) with one exception. Data for TPM; Screedmen (A), reference 9, were taken from the original report due to inability to corroborate with data reported by NIOSH. European data (Norseth et. al.) was excluded from this analysis since this analysis is U.S. specific.

b) Data for references 3, 4 and 12 were taken from original reports published since the NIOSH Hazard Review (2000)

c) Entries with an asterisk (*) indicate that these data were not reported.

d) Reference 3, Kriech et. al. 2002 includes data from sites employing pavers with and without engineering controls.

e) Reference 12, Michelsen et. al. 2006 data are the arithmetic means of measurements taken at 11 different sites where all pavers were equipped exclusively with engineering controls.

By Number

1 Gamble et al. 1999
2 Hicks 1995
3 Kriech et al. 2002
4 McClean et al. 2004a
5 Miller and Burr 1996b
6 Hanley and Miller 1996b
7 Kinnes et al. 1996
8 Almaguer et al. 1996
9 Miller and Burr 1996a
10 Miller and Burr 1998
11 Hanley and Miller 1996a
12 Mickelsen et al. 2006

In order to examine the entire data set (by task) a statistical summary was generated by calculating the arithmetic means of the study data geometric means and the 95% confidence intervals, weighted by number of samples in each specific task study population (Table 4.4b). As evidenced by this analysis the exposure hierarchy from highest to lowest is as follows: Screedmen, pavers, rakers, rollers, an order that is entirely consistent with the hierarchy established above for European paving workers.

Table 4.4b. Consolidated Summary (By Task) of Personal Airborne Exposure Data Reflected in Table 4.4a. U.S. Open Paving Sites — Total Particulate and Benzene Soluble

Measurement type	*Job category*	*Total number of samples*	*Mean among studies (95% CI, mg/m³)*	*Minimum mean among studies*	*Maximum mean among studies*
Total particulate	pavers	76	0.36 (0.32,0.39)	0.009	0.85
	rakers	116	0.31 (0.29,0.33)	0.031	0.66
	screedmen	107	0.37 (0.33,0.41)	0.078	0.72
	rollers	50	0.15 (0.13,0.17)	0.040	0.36
	Overall	401	0.32 (0.31,0.32)	0.009	0.85
Benzene solubles	pavers	69	0.16 (0.12,0.21)	0.005	0.59
	rakers	84	0.10 (0.08,0.11)	0.010	0.31
	screedmen	79	0.17 (0.10,0.24)	0.005	0.37
	rollers	25	0.04 (0.03,0.06)	0.014	0.07
	Overall	272	0.13 (0.12,0.14)	0.005	0.59

[A] The weighted arithmetic means among the study data (Y in the equation below) were calculated by summing the products of each study's number of samples (ni, column 3 in Table 1) and reported mean concentration (yi, column 4 in Table 1), and then dividing this sum by the total number of samples in all the studies:

$$Y = \frac{\sum (n_i \cdot y_i)}{\sum n_i}$$

The 95% confidence intervals were calculated as:

$$CI = Y \pm t_{(\alpha/2, N-1)} s/\sqrt{N}$$

Where s is the sample standard deviation (see below), N is the number of studies, is the desired significance level (1-CI, or 0.05), and t(/2, N-1) is the upper critical value of the two-sided t distribution with N-1 degrees of freedom.

The sample standard deviations (s) were calculated using a similar weighting as for the means:

$$s = \sqrt{\frac{\sum \left(n_i (Y - y_i)^2\right)}{\left(\sum n_i\right)(N-1)}}$$

Table 4.4c. Personal Airborne Exposure Levels Measured at U.S. Paving Site In a Tunnel (Sylvain and Miller, 1996)

Measurement type	*Job category*	*Number of samples*	*Geometric Mean (mg/m³)*
Total particulate	pavers	1	1.9
	rakers	6	1.5
	screedmen	1	1.5
	rollers	1	2.1
Benzene solubles	pavers	1	1.1
	rakers	6	0.44
	screedmen	1	0.91
	rollers	1	0.87

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