THE BITUMEN INDUSTRY

— A Global Perspective

Production, chemistry, use, specification and occupational exposure

THIRD EDITION

A Joint Publication of

asphalt institute | eurobitume

IS-230

THE **BITUMEN** INDUSTRY

— A Global Perspective

Production, chemistry, use, specification and occupational exposure

The Asphalt Institute is the international trade association of petroleum asphalt producers, manufacturers and affiliated businesses. Founded in 1919, the Asphalt Institute's mission is to promote the use, benefits and quality performance of petroleum asphalt, through engineering, research, marketing and educational activities, and through the resolution of issues affecting the industry.

Eurobitume is the European industry association for the producers of refined bituminous products in Europe. The organisation was founded in 1969 and is based in Brussels, Belgium. Eurobitume is a non-profit organisation and works to promote the efficient, effective and safe use of bituminous binders in road, industrial and building applications.

INFORMATION SERIES NO. 230 (IS-230)

Printed in USA
Third Edition
ISBN 978-1-934154-73-1

CONTENTS

1. Scope

This document provides a description of the manufacture, blending, modification, chemistry, use, specification and occupational exposures related to bitumen from the refiners' perspective. It covers bitumen produced by petroleum (crude oil) refining including those crude oils sourced and processed from oil sand and oil shale deposits. Although other bitumen-like deposits exist, such as natural asphalt, lake asphalt and rock asphalt, the term "bitumen" in this document refers only to product obtained from petroleum through various refining processes. While comprehensive, it is only a summary of large amounts of information related to bitumen. For further information, the user is encouraged to review the documents referenced in the Bibliography or contact the Asphalt Institute or Eurobitume.

2. Introduction

Bitumen is manufactured from the distillation of crude oil during petroleum refining. It is produced to meet a variety of specifications based upon physical properties for specific end uses. Its main characteristics as an adhesive, as well as being waterproof, thermoplastic, durable, modifiable and recyclable make it ideal as a construction and engineering material.

Asphalt Institute and Eurobitume estimate that the current world production of bitumen is approximately 87 Million tonnes per year. Figure 1 shows estimated bitumen use and application by sector. There are more than 250 known applications of bitumen, with the majority of bitumen being used in paving and roofing applications:

- 85% of all the bitumen is estimated to be used as the binder in various kinds of asphalt pavements: pavements for roads, airports, parking lots, etc.[1] [2]
- About 10% of the bitumen is estimated to be used for roofing: shingles, hot applied built up roofing, cold applied roll on roofing.[3]
- The remaining part (approximately 5% of the total), is used for a variety of applications each small in volume: e.g. sound deadening, water pipe coating, bitumen paints, waterproofing and sealing materials. This sector is referred to as "Other applications".

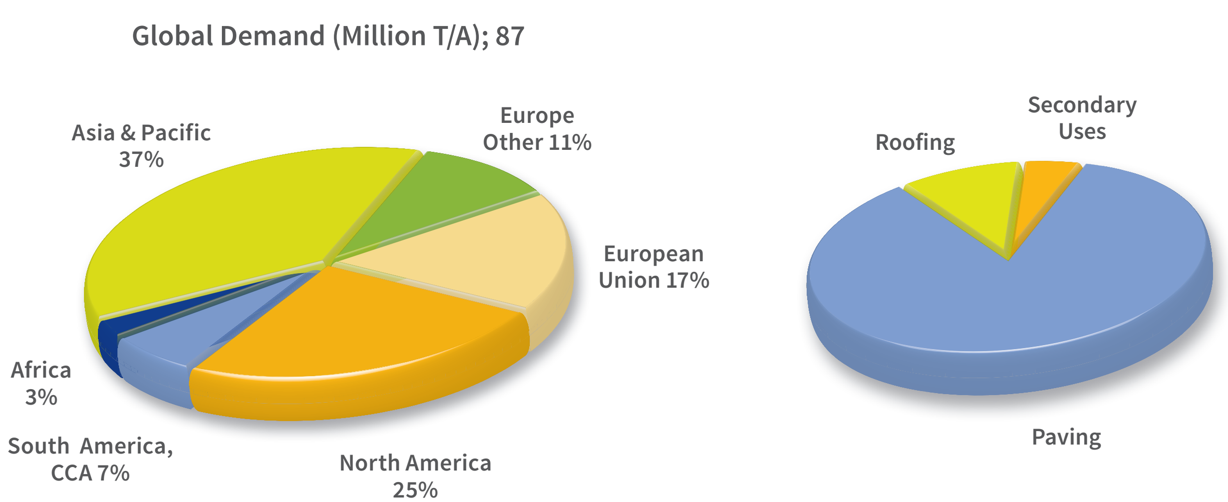

Figure 1. Global bitumen use (Source: Asphalt Institute & Eurobitume)

Most bitumen is applied at elevated temperatures within construction materials. Specifications are based on regional climatic factors described in terms of engineering properties (consistency, stiffness, viscosity, material strength/cohesion, adhesion and ageing/durability).

Properties and quality of bitumen depend mainly on the crude oil used in its manufacture. It is produced to grade specification either directly by refining or by blending. Polymers and additives are sometimes used to modify the thermoplastic characteristics of bitumen to enhance final product performance.

"Straight-run bitumen" is the term used for residuum from (vacuum) distillation of crude oil. Residuum from further refining during the deasphalting process may also be blended with straight-run bitumen. Bitumen can be further processed by blowing air through it at elevated temperatures (air-rectification, or oxidation) to alter its physical properties to meet product specifications. Petroleum streams inside the refinery used in the manufacture of bitumen are classified typically by CAS Registry Number and/or EINECS (see glossary, Appendix 1 for a definition). A summary of CAS/EINECS numbers that have been used, or are available for use in bitumen products is given in Appendix 2.

Chapter 3 of this publication describes how bitumen is manufactured. Bitumen is generally not used on its own but as a component of various end-use bituminous products which are described in Chapter 4. Chapter 5 provides an overview of the physical properties and chemical composition of bitumen.

Bitumen is normally applied at elevated temperatures which may give rise to emissions from hot bitumen which in turn could lead to exposure in an occupational setting. Occupational exposure to hot bitumen emissions is strongly related to temperature of application. Chapter 6 describes bitumen emissions, their temperature dependence, occupational exposure and exposure measurements related to working with hot bitumen.

Chapter 7 concludes with health and safety considerations when working with hot bitumen.

2.1. Terminology

Petroleum bitumen is known by different names throughout the world. For example the term "bitumen" is typically used in Europe and is synonymous with the term "asphalt", or "asphalt binder" used in North America. Outside North America, the term "asphalt" is used to describe mixtures of bitumen with mineral materials. In this document the term bitumen will be used to represent all bitumen and products manufactured.

Coal derived products such as coal tar or coal-tar pitches are very different from bitumen. These are manufactured by the high-temperature pyrolysis (>800°C) of bituminous coals and differ from bitumen substantially in composition, physical characteristics, and potential health risks. These differences are well defined in the literature.[4] [5] [6]

Petroleum pitches, which are often highly aromatic residuums, produced by thermal cracking, coking or oxidation from selected petroleum fractions are also significantly different from bitumen.

Bitumen also should not be confused with natural or lake asphalt such as Trinidad Lake Asphalt, Gilsonite, rock asphalt and Selenice that are sometimes used as additives in end use applications. These products are unrefined and not produced by refining of crude oils. They often contain a high proportion of mineral matter (up to 37% by weight[7]) and light components, leading to a higher loss of mass when heated.

A glossary of terms appears at the end of this document (Appendix 1).

2.2. Bitumen identification and specifications

Global substance inventories vary by region by virtue of differences in legislation. In Europe a total of nine CAS numbers cover refinery streams that may be used in bitumen manufacturing. Not all nine are registered in REACH and the majority of bitumen relates to three CAS registry numbers; (1) Asphalt, (2) Residues Vacuum and (3) Asphalt, Oxidized.[8] In North America, all products in commerce are listed either on the US EPA TSCA or Canadian Domestic Substance List DSL, or non-domestic substances list (NDSL), and are identified in terms of three substances ("Asphalt", "Asphalt Oxidized" and "Vacuum Residue").

Systems to specify bitumen vary by region and application and are based on physical properties of the bitumen. Specification systems are developed by national or regional standardisation bodies (e.g. AASHTO, ASTM, Austroads, CEN, Chinese Ministry of Communications), although proprietary products are also produced for specialised applications and for which a national specification does not exist.

Because bitumen is an engineering material specifications are generally based around physical properties relating to the intended use. For paving bitumens examples of specifications include AASHTO M320 (USA), EN 12591 (EU); for roofing bitumens ASTM D312 (USA) and EN 13304 (EU). The specifications use harmonised test methods which also vary by region and intended use.

3. Bitumen manufacturing

Bitumen is primarily obtained by vacuum distillation of carefully selected crude oil or blends of crude oil. It comprises the non-distillable fraction, often technically referred to as (vacuum) residue. In its simplest form bitumen manufacturing separates the lighter, low boiling point fractions from crude oil resulting in product with high boiling point, high molecular weight with very low volatility. Properties and quality of bitumen depend mainly on the crude oil(s) used in its manufacture. It is produced to grade specification either directly by refining or by blending. Bitumen can be further processed to alter its physical properties in order meet certain specifications.

Several manufacturing methods are available to produce bitumens depending on the crude source(s) and processing capabilities available within a refinery.[9] [10] [11] Often a combination of processes are selected.

3.1. Crude oil analysis and selection

Petroleum residuums from the distillation of crude oils are the starting materials for bitumen production. Therefore the properties of the bitumen depend upon the properties of the crude oil from which the bitumen is manufactured. The crude oil or blends of crude oils can come from several sources, those that would be considered naturally occurring and those created or extracted from oil sands or shale. Of the multitude of crude oils or blends commercially available, only a limited number are considered suitable for producing bitumen of the required quality in commercial quantities. In general heavy (Specific Gravity >0.9) crude oils are used to produce bitumen of the required quality. These types of crude oils tend to contain higher sulphur contents (>1 %m).

Bitumen, as a fraction of suitable crude oils, typically ranges between 20–50 %m. In modern, integrated refineries a common practice is to blend multiple crude oils to produce consistent quality bitumen that meets the engineering specifications. Therefore the compositional analysis of bitumen produced by a given refinery will not vary greatly. Further, the nature of petroleum refining processes means that bitumens from different sources of supply are expected to be qualitatively similar.[12]

3.1.1. Oil sand, Oil shale and Shale oil

There are vast reserves of oil sand and oil shale deposits and, as it becomes economically more attractive to extract the hydrocarbons from these deposits, the production continues to grow rapidly.

Oil sands are a mixture of sand, water, clay and heavy hydrocarbon deposits. These oil sands are extracted either by open cast mining or by in-situ heating in the ground and brought to the surface once it is able to flow. It is then processed at the source to remove the non-hydrocarbon impurities, and then can either be hydrotreated to create lighter synthetic crude or blended with a light condensate to create what is known as a “dilbit” crude oil. This is in order to be able to transport them easily to a refinery for distillation and processing.

Oil shale is a fine grained rock containing a compound known as kerogen. This substance is the precursor to the formation of crude oil and gas and generally has not been buried deep enough or become hot enough to form conventional crude oil and gas. It is extracted in similar ways to oil sand, but needs converting to hydrocarbons by heating to high temperatures in the absence of oxygen. It can then be transported to refineries for conventional processing.

Shale oil, more commonly known as tight oil, is different from oil shale in that it refers to oil trapped in low porosity rock which can be extracted by hydraulic fracturing or “fracking”. Tight oil is generally light, ‘sweet’ crude oil which is not suitable for bitumen production as it lacks the high molecular weight components essential for bitumen.

3.2. Distillation

The most common refining process used for producing bitumen is straight reduction to grade from petroleum crude oil or a crude blend, using atmospheric and vacuum distillation. In the schematic, atmospheric distillation is used to physically separate light, lower boiling point, petrochemical and fuel fractions from the non-boiling component known as atmospheric residuum.

To remove the last traces of the lighter fractions, and avoid thermal transformation of the molecules, the atmospheric residuum is introduced into a vacuum distillation unit. At reduced pressure it is possible to separate out any remaining lighter fractions, as the boiling temperatures are lower and unwanted thermal cracking of the molecules is avoided.

The lighter fractions, for example vacuum gas oils, are removed at atmospheric equivalent temperatures of 345–400°C (650–750°F) and 370–450°C (700–850°F) leaving a high boiling point, high molecular weight hydrocarbon residuum. The atmospheric equivalent temperature to yield the vacuum residuum is typically up to 535°C (1000°F) and has a low volatility.

Depending upon the specification grade requirements the vacuum residuum can be used either directly, further processed, or used as a component of blended bitumens.

The non-distillable materials produced by distillation of atmospheric residuum under vacuum are described by Asphalt (CAS# 8052-42-4) and Residues (petroleum) vacuum (CAS# 64741-56-6).

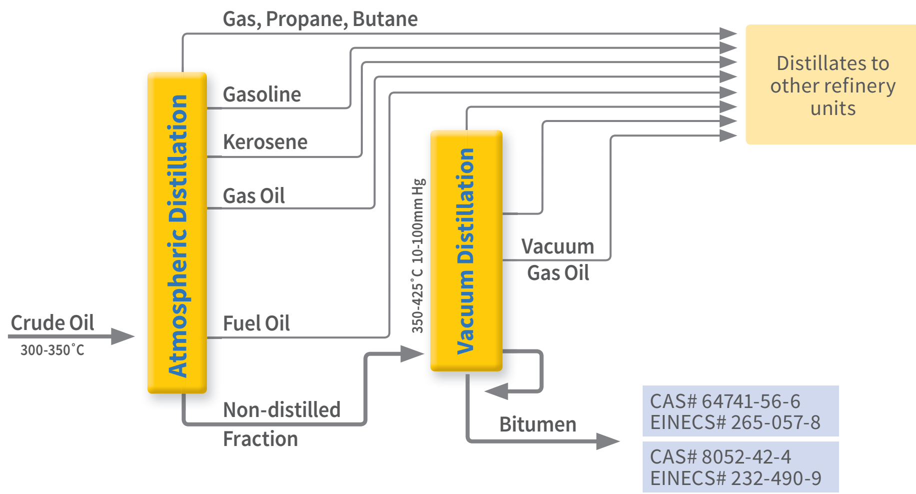

Figure 2. Schematic diagram of the distillation process

3.3. Air rectification

A mild degree of air-blowing, known as air rectification, is commonly used to make minor adjustment to the physical properties, such as decreasing the penetration and/or increasing the stiffness of the bitumen. The feedstock for air-rectification is vacuum residuum and/or bitumens not meeting the required technical specification.

Air-rectified bitumens are predominantly used in paving applications and application temperature is equal to paving application temperatures using straight-run bitumens. Other applications may also include roofing and industrial coatings where straight-run bitumens are normally used. Air rectified bitumen materials are also used for the production of polymer modified binder grades and as the base bitumen for the production of bitumen emulsion. Air-rectified bitumen products are not differentiated from straight-run bitumen products conforming to the same specification.

In Europe air-rectified products have Penetration Index (PI) ≤ +2.0

3.4. Solvent deasphalting

The properties of the vacuum residuum can be modified by use of subsequent refining process steps. Solvent deasphalting or the ROSE (Residual Oil Solvent Extraction) process, [13] uses propane, butane, isobutene, pentane, or supercritical solvent extraction to separate asphaltene-type fractions from residuums for producing lubricating oil base stocks. The hard bitumen remaining after solvent deasphalting can be blended to produce specification grade bitumen.

The residual products produced by processing through a solvent deasphalting unit are described by Asphalt (CAS# 8052-42-4), Asphaltenes (CAS# 91995-23-2) and Petroleum Resins (CAS# 64742-16-1) depending upon the process used.

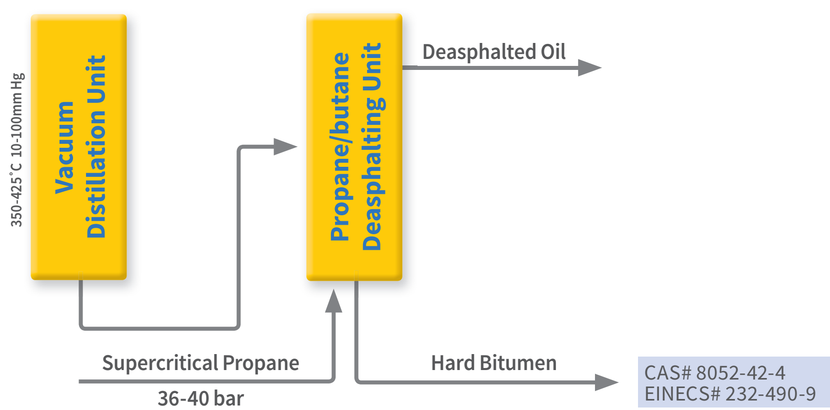

Figure 3. Schematic diagram of the propane deasphalting process

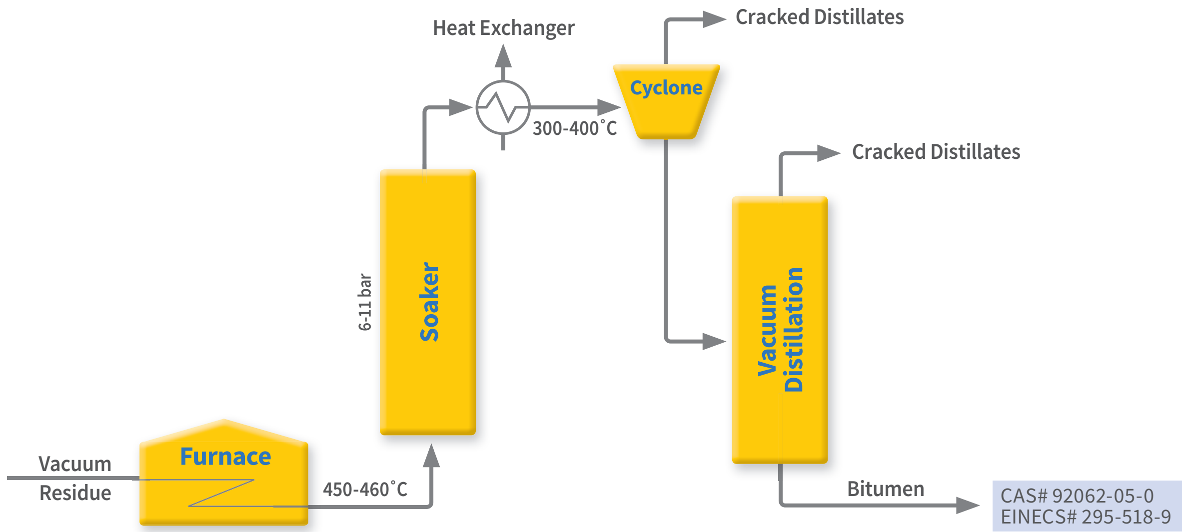

Figure 4. Schematic diagram of the thermal cracking process

3.5. Vacuum distillation of thermal cracked residuum

In a visbreaking unit, a residue stream (either atmospheric, or vacuum residuum) is heated to temperatures between 440–500°C (825–930°F). Process conditions vary depending upon the feedstock, the desired properties of the thermally cracked material and to avoid coke formation. Long paraffinic side chains attached to aromatic rings are the primary cause of the high pour point and viscosity seen with residue streams. Visbreaking is carried out under conditions optimised to break off these long side chains and subsequently transform them to form shorter molecules with lower viscosity and pour point.

When used for bitumen production the thermally cracked residuum is subjected to vacuum distillation to remove the distillate fractions which are then further treated and used in production of fuels. The product obtained after vacuum distillation is typically a hard material which can be used as a blending component for bitumen production.

3.6. Oxidation

Oxidised bitumen, also known as blown bitumen, is produced in a bitumen oxidation unit. This process involves passing 85 - 140 m^3/min of air through bitumen feedstock at elevated temperatures in order to change the physical properties of the products. The main purpose is to stiffen the bitumen, as measured by an increase in softening point, decrease in penetration and an increase in viscosity. The process achieves this through varying degrees of chemical reactions which results in an increase in the apparent molecular weight and polarity of the bitumen.(14) (15) (16) (17) (18)

A catalyst may be used to increase the speed of the reaction and improve temperature susceptibility of the product relative to oxidation without a catalyst. Catalysts include materials such as ferric chloride, hydrochloric acid, phosphorous pentoxide, or phosphoric acid. Although referred to as catalysts, some of the materials used are consumed during the reaction and are therefore not true catalysts. In Europe a flux (see glossary) is sometimes added to the feed to the oxidation unit.(19)

The bitumen oxidation unit consists primarily of a reactor vessel, air blower, off-gas treatment facility and temperature control equipment. The reactor is often an empty vessel, but may contain baffles or a mechanical agitation system to ensure turbulent mixing of the bitumen with air. The oxidation reaction is generally exothermic; therefore the reactor may

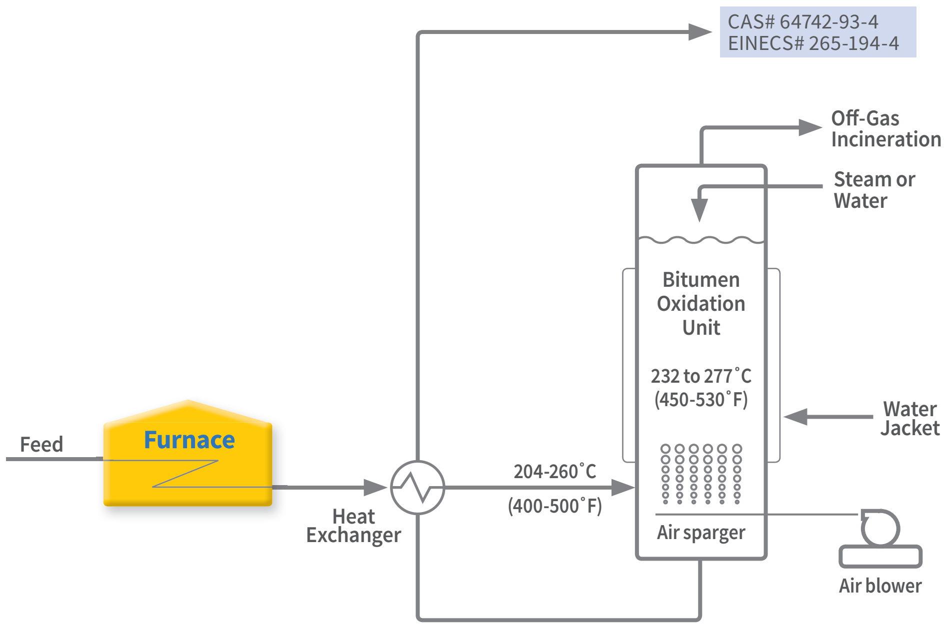

Figure 5. Schematic diagram of the bitumen oxidation process

be fitted with a water jacket and/or a water spray facility at the head of the reactor, or internal addition of water, to control bitumen temperature. Injection of steam/water into the reactor head space may also be used to reduce the oxygen content of the off-gases in order to manage the risk of fire or explosion.

The rate at which the oxidation reactions occur is affected by feedstock properties, e.g. viscosity, penetration, and reactivity. The reaction rate is also affected by the operating parameters of temperature, air flow rate, degree of agitation, pressure, air to feed ratio, and whether or not a catalyst is employed.

A schematic diagram of a bitumen oxidation unit is provided in Figure 5.

3.7. Other processes

A number of other refinery processes are used to produce small amounts of bitumen. These are primarily ‘further’ treatment or extraction processes applied to residual materials, to remove or convert constituents that are unsuitable for bitumen product performance and produce feedstocks for other processes. The processes, including hydrodesulphurisation and hydrogenation are not commonly used and hence represent only a minor part of the overall bitumen production.

3.8. Bitumen blending

Bitumen is produced to meet specifications either directly in the refining process, or by blending with bitumen having different physical properties. Higher viscosity products or bitumen may be blended with lower viscosity products or bitumen in suitable proportions to satisfy final specification requirements. Specifications are covered in section 2.2. Blending may take place at the refinery, terminals, or at a third-party facility where blend components and finished products can be easily transported by truck, rail, or barge to their final locations.

Not all blends of bitumen streams during manufacture meet the definition of bitumen and are more appropriately considered mixtures. Guidance on the distinctions between bitumen substances and mixtures has been developed by Eurobitume for specific application to the European REACH regulation.[8] Appropriate definition as bitumen or as a mixture may have regulatory implications including hazard classification and communication. Any hazard or risk transferred to a bitumen mixture from a component substance, for example refinery streams rich in PAHs, should be identified, e.g. if above a regulatory threshold.

4. Bituminous products

Bitumen is generally used as a raw material in manufacture of various end use bituminous products rather than in its as refined state. In such products bitumen is often the principal component, but they may contain significant proportions of other materials. Most bitumen is supplied directly to a downstream user for processing and application. There are numerous low volume applications in which bitumen is used, such as sound deadening, water pipe coating and sealing materials. In almost all applications bitumen is used in conjunction with other materials, for example hot mix asphalt is comprised of approximately 5 %m bitumen and 95 %m mineral aggregate.

Products which are mixtures of bitumen with non-bituminous components can be classified as modified bitumen. Modification methods to improve properties of bitumen for desired end use characteristics have been utilised for about as long as bitumen has been used. Modification techniques are primarily dependent on the desired performance of the final product and product specifications. Examples of modified bitumen products may include but are not limited to three general classifications: addition of special fillers or extending agents, chemical modification and polymer modification.

If appropriate, any hazard or risk transferred to the bitumen product by the use of additives should be identified.

4.1. Cutback and fluxed bitumen

These are products whose viscosity has been reduced or “cutback” by the addition of a volatile cut-back solvent, such as petroleum naphtha, white spirit (Stoddard solvent), kerosene, or gas oil.

Fluxed bitumen (see glossary for a definition) generally uses a relatively non-volatile solvent oil which softens the bitumen without increasing the volatility of the bitumen.

4.2. Bitumen emulsion

An emulsion is a dispersion of one immiscible liquid in another, stabilised by an emulsifier. In a typical bitumen emulsion the bitumen is dispersed in water and the emulsion is stabilised with a surface active agent (surfactant) which is tailored to the intended use of the emulsion. The dispersed droplets may have a net electrical charge which can be positive, negative, or uncharged depending upon the surfactant employed. The binder can be either a bitumen, a cutback, or modified bitumen.

4.3. Chemical modification

Chemical modification is often used to address specific performance. Chemical methods may include:

- Adhesion Promoters (e.g. fatty amine derivatives, imidazolines)
- Phosphorous Compounds (e.g. phosphorous pentoxide, polyphosphoric acid)
- Elemental Sulphur
- Maleic Anhydride
- Warm Mix Systems (e.g. Utilising surfactants or chemical lubricating additives)

Chemical modifiers are generally utilised at levels below 1 %m, as are many of the warm mix systems based on additives blended into the bitumen.

4.4. Polymer and rubber modification

Polymer modification is widely used with polymers added to bitumen for many reasons. Natural and synthetic polymers have been used since the early 20th century to improve bitumen properties. Since the mid-1960s many polymers have been used in bitumen to enhance its properties:

- Natural Polymers (e.g. Lignin)
- Thermoplastics/plastomers (e.g. polypropylene, polyethylene, ethylene vinyl acetate)
- Elastomers (e.g. natural rubber, synthetic rubber, polybutadiene, butyl rubber)
- Thermoplastic Elastomers (e.g. styrenic block copolymers, polyolefin blends, thermoplastic polyurethane)
- Ground Tyre Rubber (e.g. reclaimed scrap tires)

Polymer additives generally range from 1 %m to typical levels of 3 %m, to as much as 7 %m of the total binder for some applications. Of those listed above, thermoplastic elastomers account for largest use of polymers in bitumen modification. These products typically stiffen bitumen at high temperatures and make bitumen less brittle at low temperatures with their rubber characteristics giving bitumen the best blend of properties to address desired performance characteristics depending on end use.

Ground tyre rubber (crumb rubber), which has been used regionally for approximately 30 years, can range from as little as 5 %m to as much as 20 %m of the total binder, depending on the properties being targeted. Within the past five years efforts to eliminate stockpiles of discarded tyres have resulted in more widespread use of crumb rubber in bituminous blends.

4.5. Fillers and extending agents

Addition of special fillers or extending agent is likely the oldest method of bitumen modification used to improve stiffness and viscosity characteristics including additives such as:

- Mineral Fillers (e.g. limestone, fly-ash and clay)
- Adhesion Promoters (e.g. hydrated lime)
- Fibers (e.g. natural - cellulose, synthetic - polypropylene)
- Natural Asphalts (e.g. Trinidad Lake Asphalt, Gilsonite)
- Recycled Asphalt Materials (e.g. recycled asphalt pavement and recycled asphalt shingles)
- Waxes (e.g. synthetic, such as Fischer-Tropsch, natural, such as Montan and amide derivatives such as Ethylene Bis-stearamide)
- Bio-binders (e.g. vegetable based components, animal by-products and waste)
- Warm Mix systems (e.g. synthetic and natural waxes)
- Products from re-refining of used oil (see glossary for a description of materials used)
- Sulphur

In some processes, typically for chemical modification, elemental sulphur constitutes only a minor amount (<1 %m) and is used to cross link styrene-butadiene polymers, but may comprise up to 40% by total binder weight when used to produce a sulphur- extended asphalt. Concerns regarding emission of H_2S and other sulphur compounds during initial construction and during recycling have slowed the adoption of sulphur as a bitumen extender.

5. Physical properties and chemical composition of bitumens

The manufacturing processes for bitumen that are described in section 3 involve the removal of lighter components to leave behind relatively high molecular weight, low volatility compounds.[20] The resulting products all are generally solid, or semi-solid materials at ambient temperature and they soften as the temperature increases.

The vapour pressure of in-situ bitumen is below the limit of detection for normal instrumentation. Bitumen is normally heated to >140°C (284°F) to become liquid to facilitate transportation and handling.

Some of the performance-related physical properties are regulated by national, or international specifications, while other properties, like specific gravity or vapour pressure, result from the manufacturing processes used to meet the performance specification.

5.1. Physical properties

Bitumens are thermoplastic solids, or semi-solids at ambient temperature, i.e. they soften as the temperature increases and harden as the temperature decreases. At elevated temperature they behave as Newtonian liquids, the viscosity reducing with increasing temperature. This is the reason that bitumens must be heated for handling and application in their intended use.

Bitumens are also visco-elastic materials, i.e. they behave as elastic solids at short loading times and as viscous liquids at longer loading times.

Polar molecules in bitumen lead to bitumen having an affinity to aggregates, providing a material that is adhesive and also waterproof.

Bitumens are engineering products and therefore the product specifications focus on defining physical properties, rather than being based upon chemical composition. The properties of the substances manufactured in the refinery can also be modified for specific end-uses by modifiers described in section 4.

The physical properties of the bitumen not only determine the suitability for a given application, but also define the conditions under which the product must be handled in order to enable the product to be placed in the structure in which it is to be used.

5.1.1. Temperature susceptibility

In order to perform over a wide range of ambient temperatures it is desirable that some products exhibit reduced temperature susceptibility. A number of methods exist to determine the change in properties with temperature of a given bitumen which relate to a change of physical properties, such as stiffness, or penetration value[21] with temperature. One such method, used in Europe, is the Penetration Index (PI).[22]

Bitumen oxidation modifies the penetration-softening point relationship, reducing the temperature susceptibilty of the material, resulting in a systematic increase of the PI of the oxidised substance. Therefore PI is considered to be a good indicator of the level of oxidation.

Other methods can be used to determine the temperature susceptibility of bitumens.

5.2. Chemical composition of bitumen

The chemical composition of bitumens is generally similar, but with some variation depending upon the original crude oil and on the processes used during refining and blending. Bitumens can generally be described as complex mixtures of hydrocarbons containing a large number of different chemical compounds of relatively high molecular weight. There is considerable uncertainty as to the molecular weight distribution of bitumen. The smallest size, approximately 300 Dalton, is determined by the distillation 'cut point' during the manufacture of the bitumen. The largest size has not been finally concluded; earlier research suggested that molecular weights up to 10000 Dalton are present,(23) while some research(20) indicates that there are probably very few, if any, molecules larger than 1500 in bitumen.(24) (25)

The molecules present in bitumens are combinations of alkanes, cycloalkanes, aromatics and heteromolecules containing sulphur, oxygen, nitrogen and metals.(26) A typical elemental analysis is given in Table 1.

Bitumen functionality relates to how molecules interact with each other and/or with other materials, e.g. aggregate surfaces and water. The content of sulphur, nitrogen, oxygen and metals in some molecules makes them slightly polar. The significance of molecules containing hetero-atoms in bitumen chemistry is the ability to form molecular associations, which strongly influence the physical properties and performance of bitumens. The components containing the hetero-atomic compounds can vary in content and characteristics in bitumens obtained from different crude sources.

Table 1. Elemental analysis of bitumens from various sources(27)

Element	Range
Carbon, %w	80.2 - 84.3
Hydrogen, %w	9.8 - 10.8
Nitrogen, %w	0.2 - 1.2
Sulphur, %w	0.9 - 6.6
Oxygen, %w	0.4 - 1.0
Nickel, ppm	10-139
Vanadium, ppm	7-1590
Iron, ppm	5-147
Manganese, ppm	0.1 - 3.7
Calcium, ppm	1-335
Magnesium, ppm	1-134
Sodium, ppm	6-159

The sulphur content may be 1–7% by mass in bitumen and can consist of many different sulphur compounds such as thiophenes and sulphides. Studies have shown that the hetero-atoms, sulphur and nitrogen, occur largely in stable ring configurations.(28) Although nitrogen compounds are not as common, pyrrole, indole and carbazole groups are found in some bitumens. Oxygen is mainly present in functional groups as carboxylic acids and esters. The metals appear mainly in porphyrin-like structures.(23)

5.3. Chemical characterisation of bitumen

Bitumen is a visco-elastic material; therefore chemical polarity is an important property to measure. The most polar components create structural components which give bitumen stiffness (modulus) properties. Whereas the least polar components give asphalt its flexibility and low temperature properties, the intermediate polarity components in bitumen compatibilise the least and most polar components.

Since bitumen contains a continuous range of molecules it is impractical to analyze each individual compound. Common practice is therefore to divide bitumen into four broad, increasingly polar fractions: saturates, aromatics, resins and asphaltenes (SARA). The asphaltenes are usually separated using solvent precipitation while the three other fractions are defined by using chromatography.

There are several standard methods available for separation of bitumen into these four fractions and the naming of the fractions, which is not descriptive of the chemical composition, which may vary.

When bitumen is further processed such as in air rectification and oxidation the SARA analysis shows a shifting of Resins being converted to Asphaltenes and Aromatics being converted to Resins. Overall the bitumen becomes stiffer and more elastic compared to the starting bitumen.

During oxidation the primary oxidative process is carbon-carbon bond formation via oxidative condensation. Asphaltene content is increased, while the content of naphthenic and polar aromatics is decreased (see section 3.6).(15) (16) (29) As the asphaltene concentration increases beyond a certain point, the ambient temperature flow properties of the modified bitumen product change from visco-elastic to nearly pure elastic behaviour at ambient temperature.

Oxygen that is added to the bitumen in the air-blowing appears to reside in hydroxyl, peroxide, and carbonyl functional groups (ketones, acids, acid anhydrides, and esters).(30) (31) (32) Small amounts of volatile components of the bitumen are also removed during the oxidation process.(16) (17) As a result of these reactions the polycyclic aromatic hydrocarbon (PAH) content of the bitumen is reduced.(33) (19)

5.4. Polycyclic Aromatic Hydrocarbons in bitumen

Polycyclic Aromatic Hydrocarbons (PAH) are noteworthy because of their association with health effects. PAH are a subset of a broader group of polycyclic aromatic compounds (PACs) which may also contain other atoms, such as sulphur, oxygen and nitrogen.

Crude oils contain low levels of polycyclic aromatic hydrocarbons, which partly end up in bitumen at ppm levels.(34) The maximum temperatures involved in the production of bitumen, <385°C (725°F), are not high enough to initiate significant PAH formation, which requires pyrolysis or combustion and typically takes place at temperatures above 500°C (930°F).(35) The principal refinery process used for the manufacture of bitumens, vacuum distillation, removes the majority of PAHs. Also, as noted above, oxidation has also been shown to reduce overall concentrations of PAHs in bitumen.(33) (19)

The levels of some commonly measured PAHs in various bitumens are shown in Table 2.

Table 2 - PAH content of bitumen

Polycyclic Aromatic Hydrocarbons (PAH)	PAH in Bitumen (ppm) (36) (37) (38)
Naphthalene	2.5 - 3.0
Acenaphthene	BDL - 0.7
Fluorene	0.3 - 0.5
Phenanthrene	0.3 - 7.3
Anthracene	BDL - 2.0
Fluoranthene	BDL - 2.0
Pyrene	0.2 - 8.3
Chrysene	<0.1 – 11
Benzo[a]anthracene	BDL - 3.3
Perylene	BDL – 39
Benzofluoranthenes	BDL - 1.2
Benzo[e]pyrene	<0.1 - 13
Benzo[a]pyrene	BDL - 4.6
Dibenzanthracenes	BDL - 3.3
Indeno[1,2,3-cd]pyrene	BDL - 2.4
Benzo(ghi)perylene	<0.1 - 4.6
Anthanthrene	BDL - 0.1
Dibenzo[a,l]pyrene	BDL - <0.6
Dibenzo[a,i]pyrene	BDL - <0.6
Coronene	BDL - 1.9

BDL = Below Detection Limit

6. Bitumen emissions

Numerous studies have been conducted to characterise emissions of bitumen in the environment.

6.1. Water & soil

Bitumen is a very inert material that is insoluble in water.(39) (40) However, bitumen based paving and roofing materials are subject to water runoff from rainfall events. Moreover, bituminous materials are often used to line drinking water reservoirs and in products to line water pipes that supply potable drinking water.(41) Retention ponds are often paved with asphalt to keep liquid industrial waste material from leaching into the soil. Similarly, bitumen is used to line and cap hazardous waste sites – preventing rainwater from permeating through the hazardous waste and from leaching into groundwater.(41)

Heavy metal contamination of highway runoff water and roadside soils has been reported.(42) (43) (44) (45) However, further research has shown that pollutants in runoff from bitumen pavements emanate from vehicles that use the pavements, not from the asphalt pavements themselves(.46)

In 2001, Brandt and de Groot compared static leach test results with dynamic leach testing, both of which showed that the leach water from bitumens stays well below the surface water limits that exist in several European community countries and are more than an order of magnitude lower than the limits for potable water.(39)

In 2002, Kriech examined six paving and four roofing bitumen samples to determine the concentration of 29 PACs in leachate waters under laboratory conditions.(38) The majority of results were below detection limit by the GC/MS methods of analyses employed. Those materials detected were further verified by GC/MS/MS analyses. Two of the 290 results were above the detection limit of 1 ppb; naphthalene was found in one paving sample (1.8 ppb) and phenanthrene was measured in another paving sample at 1 ppb.(47)

The Department of Ecology with the state of Washington performed a Toxic Chemical Assessment study at the Puget Sound from 2007-2011.(48) Based on results of these studies, they conducted an assessment of roofing materials in the Puget Sound basin to determine whether roofing materials contributed to releases of the toxic chemicals that they found. They assessed roofing materials using a well-designed controlled study over a two year period. Analysis of the runoff water included metals (arsenic, cadmium, copper, lead, and zinc) and organics (PAHs, phthalates, polybrominated diphenyl ethers). They collected 10 rain events during a three month span then 6-months later, collected 10 rain events during a 4 month span to assess the effects of aging. Across the 20 rain events, results showed that asphalt shingle, built-up, and modified-built-up did not release elevated levels of the metals or organic compounds evaluated in runoff, with levels low and generally not distinguishable from control panel levels. The bitumen shingle panels released significantly lower concentrations of copper during Round 2 after aging.

The National Cooperative Highway Research Program sponsored a research team at Oregon State University to develop a methodology to screen common highway construction and repair materials for potential impact on the quality of surface and ground waters. Results of laboratory testing and a first-level screening tool are presented in a series of U.S. Government publications.(49) (50) The study reported that "The materials conventionally used in pavements have been found to pose no harm to the environment." The study further found that construction and repair materials containing crumb rubber, shingles, foundry sand, and municipal solid waste incinerator bottom ash exhibited significant toxicity to algae and daphnia. The study further found reduction in toxicity after they were incorporated into paving or fill and even more so after sorption.(49) (50)

The National Sanitation Foundation conducts testing of various materials for suitability for use in potable water system components, among its many functions. A listing of asphalt containing components certified for such use is maintained in a current state on the NSF website.(50)

Eurobitume carried out a study of the leaching behaviour of a straight-run bitumen and oxidised bitumen, together with a review of the available literature.(51) The study evaluated release of metals (As, Sb, Cd, Cr, Hg, Ni, Se, Al, Fe, Co, V, Mn), PAH, and BTEX (benzene, toluene, ethyl benzene and xylene). Results indicated that, with the exception of three PAHs (naphthalene, fluorene and phenanthrene), all analyses were below the detection limit. The PAH release was marginally above the detection limit, but was far below any regulatory limit for drinking water.

In 2004, researchers with the U.S. Geological Survey (USGS) published results of a study investigating the potential source(s) of PAHs and trace elements found in creek bed sediment near a seal-coated parking lot in Austin, Texas. Potential sources investigated included coal-tar-sealed, asphalt-sealed, unsealed asphalt, and unsealed concrete pavements. Distilled, deionized water was sprayed on sections of pavement under study in an attempt to simulate rainfall and the wash-off was collected for analyses. PAH was reported to be highest for effluent from coal-tar-sealed plots of pavement followed by asphalt-sealed and unsealed plots. Based in part on these and similar reports from other locations, some U.S. cities, including Washington, D.C., have taken action to restrict the use of coal-tar sealants. Research on this subject is continuing.(52)

6.2. Air

Due to the manufacturing process which removes the lower boiling molecules, emissions to the atmosphere do not occur under normal conditions of service. Bitumen emissions at ambient temperature are negligible. The physical properties of bitumen require that handling and application is typically carried out at elevated temperature. Under these conditions emissions from bitumen can occur.

Bitumen emissions in air are a complex mixture of predominantly hydrocarbons having a broad boiling point range. The molecular composition can include hydrocarbons covering the range from carbon numbers >C6 through to long branched chain aliphatic hydrocarbons, cycloalkanes and aromatics. Naphthalene derivatives are some of many compounds detected in these emissions.

The emission from heated bitumen is in a dynamic equilibrium as illustrated in Figure 6. Traditionally bitumen emission is the material which is measured and reported to reflect the level of potential occupational exposure.

Gas molecules and bitumen droplets are typically a minor proportion of the emissions from hot bitumen. The ratio of aerosol/mist to vapour varies with ambient and operating conditions. Typically in the aerosol, vapour ratio is in the range 5:95 – 15:85, but it should be recognised that under certain conditions, such as high temperature, the actual ratio may vary outside this range.(53) (54)

Bitumen fume is the "term of art" used to describe the emissions from heated bitumen and products containing bitumen.

Laboratory studies on bitumen emissions often require significant quantities of sample which cannot be obtained easily from field activities. The low level of emission in many applications means that prolonged sampling periods are needed to collect sufficient emissions for reliable measurement.(55) Occupational Exposure Limits (OELs) are often set for 8 hours to be representative of daily worker activities. Surrogate materials can be generated using laboratory methods which are representative of emissions to which workers are exposed. Such material is normally collected as a condensate, combining aerosol, vapours and gaseous fractions. Accordingly, any artificially generated fume condensate must be characterised and matched against emissions found in the workplace.

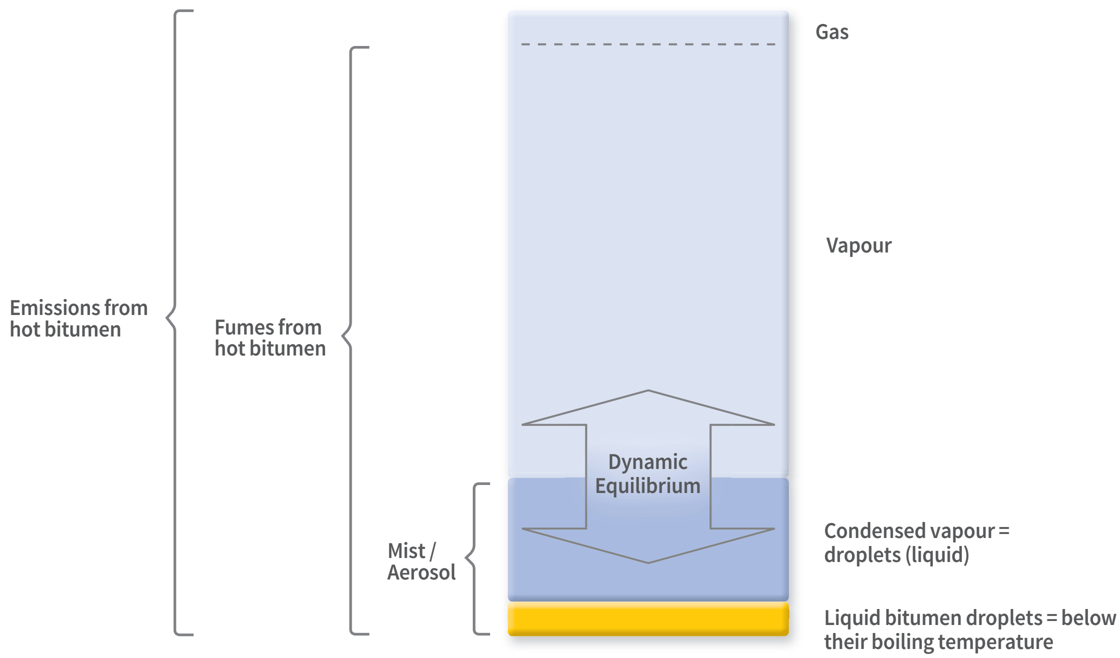

Figure 6. Schematic diagram of bitumen emissions

6.2.1. Comparison of air rectified to straight run vacuum distilled bitumen emissions

The composition of emissions from two commercial bitumens has been compared.[56] These bitumens were produced by the same refinery, from the same crude oil, but differed slightly in their processing. One bitumen was a 70/100 paving grade bitumen produced by vacuum distillation direct to grade. The second bitumen was a 50/70 paving grade bitumen produced by blending vacuum residue and air-rectified bitumen. The bitumens were produced in the same refinery as the bitumen used in the Fraunhofer-ITEM 24 month cancer inhalation study on rats.[57] An analytical comparison of the bitumens and laboratory generated emission was conducted under identical conditions. The fume generation and analysis was carried out at Heritage Research Group, USA on behalf of Eurobitume.

Emissions from the bitumens were generated in the "Heritage fume generator" at a temperature of 155°C, collected and extensively analysed to assess similarities and differences.

The emission sampling unit comprised a 37-mm total particulate sampler followed by XAD-2® plus charcoal tube as a backup. Chemical and physical analysis was carried out to characterise the bitumens.

The emissions collected on the filter and sorbent tube were eluted, combined, and analysed for simulated distillation, carbon number, and total organic matter (TOM). To investigate compounds of regulatory concern, the emissions were analysed for 33 polycyclic aromatic compounds (PACs) covering the US EPA, EPCRA, and Grimmer lists. To further characterise compounds in the bitumen emissions GC/MS was used to create fingerprints of extracted compounds.

Comparison of the emissions from the two bitumens led to the following conclusions:

- Boiling point distribution of both fume condensate samples was almost identical (See Figure 7)
- Similar ratios of semi-volatile to aerosol fractions were observed
- Similar concentrations of PACs were found in both emission samples
- The GC/MS fingerprints of both emission samples were similar in terms of compounds identified.

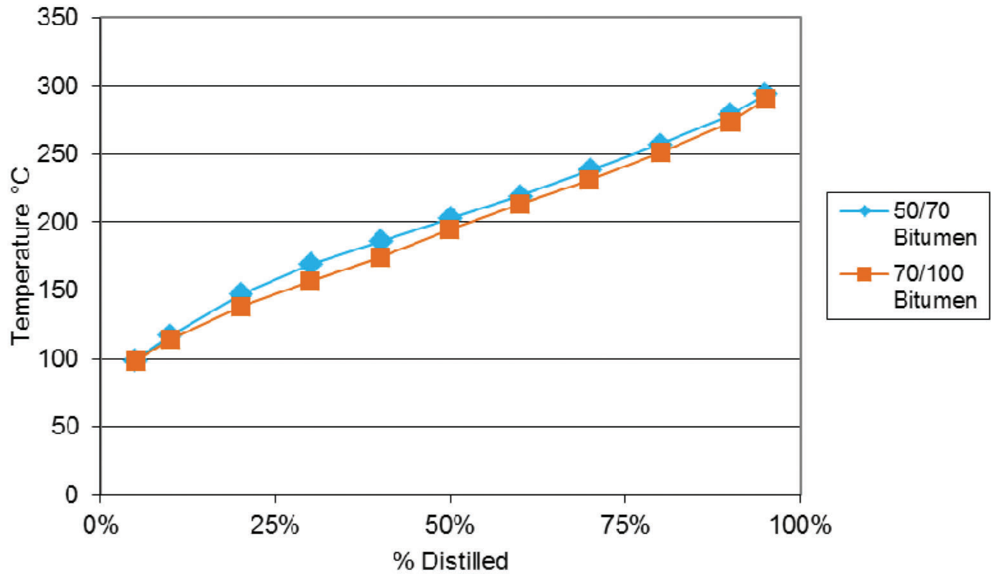

Figure 7. Boiling point distribution curves for bitumen emission samples - 50/70 (blue) 70/100 (orange).

Although some minor data variations are apparent, in general, the emissions generated from these two bitumen materials appear similar in composition and physical properties. Based on these results it is concluded that the results from the air rectified bitumen used in the Fraunhofer study can be used to 'cross-read' to similar vacuum residue and straight run paving grade bitumens (CAS # 8052-42-4 & 64741-56-6).

6.2.2. Temperature effect of bitumen emissions

During handling of bitumen, or bitumen-containing materials, at elevated temperatures, small quantities of hydrocarbon emission are released. The emissions are temperature dependent: In a laboratory study, in the temperature range relevant for paving applications [140–190°C (285–375°F)], the emission rate of the Benzene Soluble Fraction increases by a factor of 2 for about every 11–12.5°C (20–22°F) temperature increase. In the temperature range relevant for roofing applications [210–270°C (410–520°F)] it is a factor of 2 for every 14–17°C (25–30°F).(34) A second study the emissions doubled for an increase in temperature of 30°C (86°F).(58) A third study showed a 30% increase in emissions for a temperature increase of 50°C (122°F).(59)

Eurobitume conducted a study(60) to compare bitumen emissions at various temperatures, absent the confounders seen in the field. Although these laboratory- generated emissions showed differences using different laboratory rigs and actual worker exposures, this study design provided a way to control variables other than the temperature to examine the influence.

The test material was an air rectified 50/70-bitumen, similar to the bitumen used in the Fraunhofer inhalation study.(57) The same source of bitumen was used for each generation, which was heated to pre-determined target temperatures of 155°C, 180°C, 200°C, 230°C, 250°C and 300°C.

Results from this study showed that as the temperature increased the concentration of emissions released also increased. This increase in the amount of emissions produced as a function of temperature, appears to correlate logarithmically as shown in Figure 8. This relationship is predicted by the Clausius-Clapeyron equation describing the increase of vapour pressure with temperature.

An increase in fume generation temperature led to an increase in boiling point distribution of the emissions and a corresponding increase in higher molecular weight compounds. The concentration of 4-6 ring PAH increased with increasing fume generation temperature, at the same time there was a decrease in concentration of the lower molecular weight (2-3 ring PAHs).

At the 155°C generation temperature, the testing showed peaks up to ~C22. As the fume generation temperature increased up to 300°C, the peaks detected in the chromatograms showed increasing boiling points up to a carbon number of ~C34 as graphically displayed in Figure 9.(60)

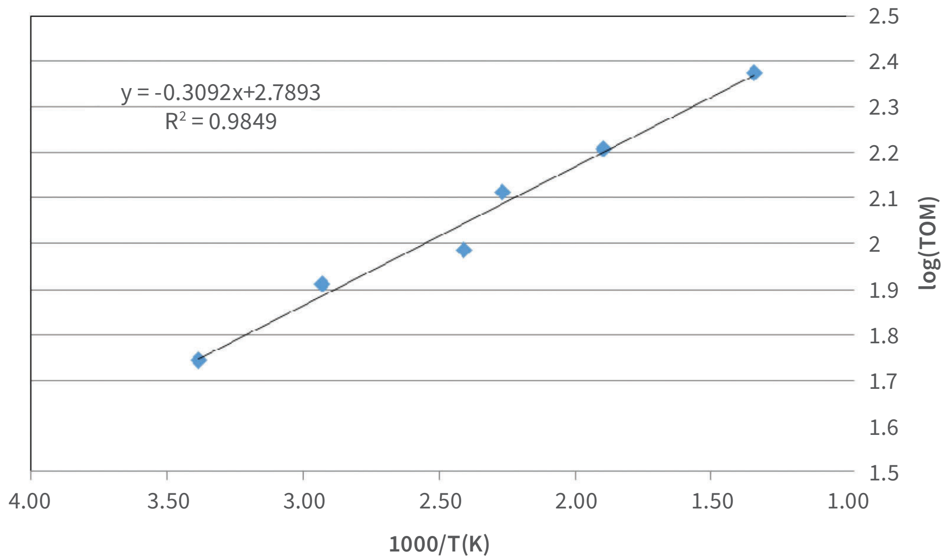

Figure 8. Log of TOM (mg/m3) as a function of the reciprocal generation temperature (1000/T, K)

In summary, for the bitumens tested, an increase in the fume generation temperature led to a positive correlation between the amount of emissions and the relative quantity of higher molecular weight substances released.

6.3. Occupational exposure from bitumen emissions

Bitumen emissions can contain small quantities of compounds that have been classified by regulatory agencies as carcinogenic or irritant. Research conducted by Eurobitume and presented in Figure 9 has shown that the quantity of emissions from bitumen is related to the temperature of the bitumen.[60] As the temperature increases the emissions also increase and can increase the occupational exposure to bitumen emissions. Thus, temperature is a key determinant for bitumen occupational exposures and therefore products containing bitumen should be handled and applied at the lowest temperature concomitant with application specifications.

Measuring exposure to bitumen emissions has continued to evolve with time. Historically exposure was more related to collecting particulate matter such as dust and aerosol found in the workplace on filters.

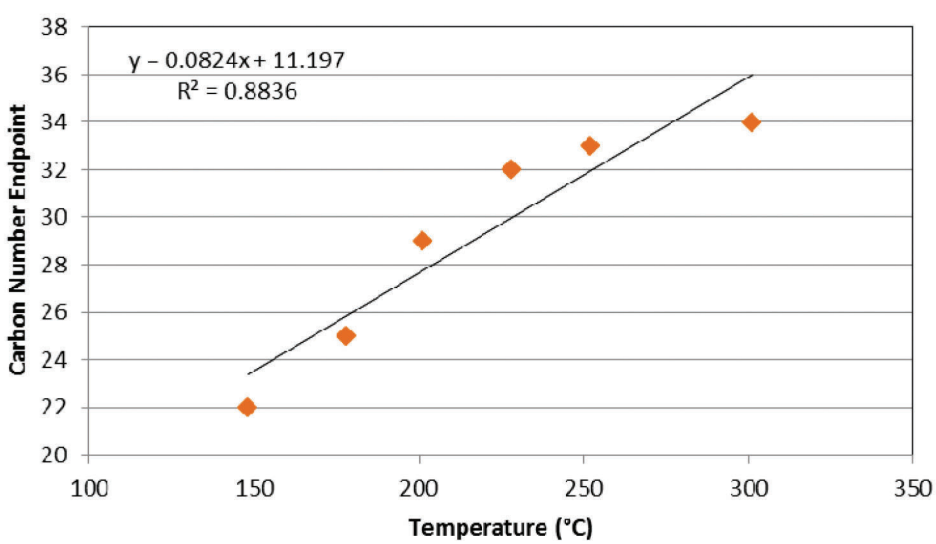

Figure 9. Fume Generation Temperature versus Carbon Number Endpoint

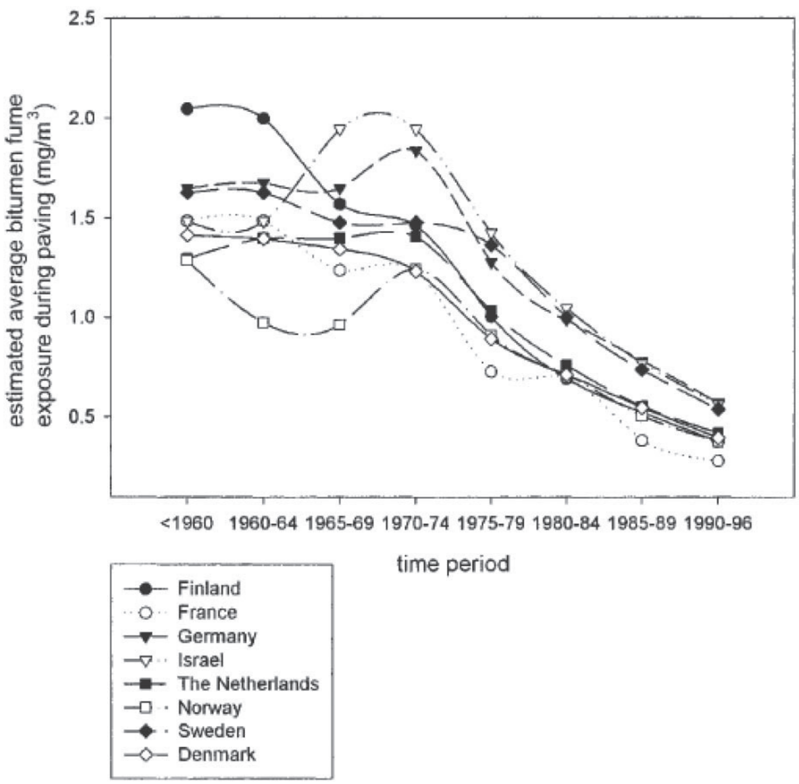

Figure 10. Assessed time trend in average exposure to bitumen emissions (pavers only).[61]

As time went on the focus shifted to compounds that caused irritation such as organic matter captured on the filter or passed through the filter to be collected on a sorbent. In more recent years the focus has shifted to measure compounds which would be potential carcinogens. To understand exposure over time it is important to use the same methods with the same endpoints to properly compare.

Two major studies looked at asphalt emission exposures over time.[61] [62] Both studies found that over time worker exposure to bitumen emissions have decreased significantly. Using multi-center occupational cohort study results, Burstyn et al., 2003 modelled that worker exposures decreased by a factor of two to three every ten years based on time trends from multivariate statistical models. Numerically, the model predicted a decrease from 1.2-2 mg/m^3 (1960) to 0.2-0.5 mg/m^3 (mid-1990s) as shown in Figure 10. After a temporary increase when recycling old asphalt with coal-tar containing layers in Europe, exposures show a steady decrease since the mid-1970s after banning the hot-recycling of coal-tar containing layers. This study also modelled trends for organic vapour and benzo[a]pyrene. Reduction of handling and application temperatures, safe handling education, use of engineering controls, alternative cleaning products are some of the factors involved in this reduction of worker exposures. Since then other developments, such as Warm-Mix Asphalt, have contributed to further exposure reduction.

Similarly, in roofing plants Fayerweather[62] shows a sharp reduction in bitumen emission exposures over time due to the addition of emission control devices, the switch from organic felt to glass mat as the core of the shingle, and a general reduction in bitumen temperatures used in manufacturing. Total particulates and the corresponding benzene soluble fraction have decreased more than 11-fold since 1977-79 in roofing plants in the study.

6.3.1. Inhalation exposure measurement

Occupational exposure to bitumen emissions is measured using a personal monitoring sampler. Collection of static or environmental samples does not provide a reliable indication of personal exposure. The type of sampler used and the method by which it is analysed can lead to substantial differences between measured values.[63] When comparing results of personal exposure monitoring surveys it is important to take into account the method used and the metric being employed. Exposure monitoring methods for bitumen emissions fall into three main categories that measure particulate matter, solvent soluble fraction of particulate matter, and organic matter.

6.3.1.1. 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. NIOSH Method 5042 refers to this measure as total particulates (TP) and represents the nonspecific gravimetric amount of organic and inorganic particles quantifying the total dust that is collected onto the filter that passes through the 4 mm inlet of the sample cassette. Sampling differences primarily involve filter type and inlet opening size affecting face velocity and capture velocity.

6.3.1.2. 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 emissions), although this gravimetric measure is also nonspecific and does not differentiate between sources of exposure. Sampling differences here include collection medium, solvent purity, and ability of selected solvent to solubilize bitumen emissions. Benzene is not used as an extraction solvent in many countries due to its carcinogenicity. 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 or inhalable fractions.[64]

6.3.1.3. Organic matter

TOM/THC (Total Organic Matter/Total Hydrocarbon): the sum of the organic part of the particulate fraction plus the organic vapour phase collected using a back-up sorbent.

In addition to monitoring exposure to bitumen emissions, some studies[65] [66] [67] [68] [69] have evaluated exposure to individual, or groups of Polycyclic Aromatic Hydrocarbons (PAHs) or Polycyclic Aromatic Compounds (PACs) as components of bitumen emissions. A number of different lists of PAHs are used because different researchers, regulators and advisory bodies have their own view of which substances should be regarded as potentially hazardous. For clarification, PAC is a more inclusive term than PAH. PAC includes PAHs, alkylated PAHs, and those multi-ringed aromatic molecules in which one or more atoms of a heteroatom such as nitrogen, oxygen or sulphur, replaces a corresponding number of carbon atoms in a ring system. Due to the complexity of bitumen emissions, with instrumentation advances, gas chromatography–mass spectrometry (GC-MS) is recommended over high-performance liquid chromatography (HPLC)[70] since similar detection is achievable, greater resolution and mass spectral confirmation.

It should be recognised that none of the methods of measuring exposure are bitumen specific but will capture particulate and vapour fractions of all organic material. Therefore exposure levels can be subject to confounding from other organic materials in the workplace, such as solvents used for cleaning and diesel engine exhaust. Complications with worker exposures in real world environments can be better understood with the aid of chromatographic methods such as GC/FID (Gas Chromatography with Flame Ionization Detection). However, quantification of these confounders can be difficult to isolate.

For each of the above categories there are numerous variables, such as type of sampler (e.g. open face, closed face, inhalable particulate), the type of solvent used to extract the filter (e.g. cyclohexane, benzene, dichloromethane), the type and quantity of sorbent used to capture the vapour phase (XAD-2®, Tenax®, activated, coconut charcoal, or a combination), duration of sampling, analytical method and flow rate of air through the filter, which may influence the measured values. The resulting differences make it difficult, if not impossible, to directly compare measurements taken using different methods.[71] [72] Many countries use GC/FID to determine the TOM/THC. On the other hand, Germany uses Fourier transform infrared (FTIR) analysis.

TOM fractions have also been analysed using fluorescence spectroscopy. NIOSH Method 5800 measures total concentrations of PACs in bitumen emissions[73] using an ultraviolet fluorescence technique used in their Health Hazard Evaluation Report.[74] Osborn et al.[75] developed a fluorescence technique to maximize the response to 4-6 ring PACs that may be present in bitumen emissions; this screening method has been used in many industry studies.[68] [76] [67] [77] [78]

6.3.2. Exposure limits

Bitumen fume-induced upper respiratory tract and eye irritation are the health-based endpoints used typically to establish workplace limit values for asphalt (fume), while cautionary statements concerning potential cancer hazard and/or absorption through the skin are often included as part of the criteria.[70]

At present, no international standardised method for sampling and measuring potential bitumen emission exposure exists. Nonetheless, occupational exposure limits for bitumen emissions have been set in over 50 countries, Canadian provinces and U.S. states. Regulatory limits in different countries and voluntary guidelines developed by independent authorities vary considerably in respect to numerical values and methods of evaluation. Appendix 3 shows examples of these limits. However, original source documents should be used to obtain the latest information.

Naphthalene is reasonably anticipated to be a human carcinogen.[79] Exposure limits include an OSHA PEL of 10 ppm (50 mg/m^3) TWA (time weighted average). However, worker exposures have been shown to be orders of magnitude below this limit with the maximum concentration at 0.014 mg/m^3 [80] (GM=0.0008 mg/m^3).

Regulatory guidelines exist for hydrogen sulphide exposure (see section 7.1.4.). The ACGIH TLV® as an 8-hr time weighted average (TWA) = 1 ppm; short term exposure limit (STEL) = 5 ppm. NIOSH recommended exposure limit (REL) = 10 ppm (15mg/m^3) as a 10-minute ceiling. OSHA has no TLV® for H_2S but has a ceiling of 10 ppm. Occupational exposure limits are similar in the UK. In 2007, the Scientific Committee on Occupational Exposure Limits for Hydrogen Sulphide recommended a 8 hour TWA: 5 ppm (7 mg/m^3) STEL (15 min): 10 ppm (14 mg/m^3).

6.3.3. Dermal exposure measurement

At ambient temperature bitumen is solid or semi-solid. Apart from physical abrasion, skin contact with solid bitumen is not expected to cause health effects. The high temperatures required to handle and apply bitumen can result in serious thermal burns if contact occurs and consequently skin contact with hot product is unlikely, except in accident situations. However, some bitumen preparations, in particular those containing diluents (see section 4.1.) to reduce the viscosity of the mixture, are handled and applied at low, or ambient temperature where skin contact may occur.

Dermal monitoring techniques are varied and no standardised approach is used by researchers.[81] Specific to bitumen workers, a variety of dermal techniques have been used. Väänänen et al.[82] used hand wipes with sunflower oil and polypropylene pads. McClean et al.[83] used polypropylene filters attached to an exposure pad. Due to limitations in the range of compounds collected, retained and recovered from existing surrogate skin samplers, Olsen et al.[84] developed a 5-layer passive organic dermal (POD) sampler. Samplers, dermal collection sites, extraction, and analytical methods are all varied, making it difficult to compare results.

Traditionally, exposure monitoring has focused on inhalation as the primary route of exposure. However, in recent years the possibility of dermal exposure and uptake of components of bitumen emissions, arising from dermal contact with condensed fumes/emissions has been considered. This section covers studies of dermal exposure to bitumen emissions. Other documents detail exposure to bitumen during handling and application of materials containing bitumen during paving, roofing and mastic asphalt operations.[1] [3] [2]

As part of a multi-country, nested case control study on lung cancer risk among asphalt workers,[85] Boffetta et al. included an assessment of dermal exposure to bitumen fume condensate, using the DREAM methodology.[86] The main skin site exposed was the hands, with direct transfer and deposition being the dominant routes of exposure. No relationship was found between dermal exposure to fume condensate and lung cancer incidence.

Skin exposure to speciated PAH compounds has been a component of several exposure assessments. One of these[87] examined workers in the U.S. employing techniques which were considered standard at the time of the study. Using polypropylene exposure pads, Fustinoni et al.[88] studied dermal exposures to 24 bitumen workers, with samples collected at the neck, shoulder, upper arm, wrist, thigh close to the groin, and the outer side of the ankle. Of these locations, the wrist showed the highest sum of PAH contamination with phenanthrene present in all samples (median 0.805-1.825 ng/cm^2).

Cavallari et al.[89] studied dermal exposures measured under three scenarios using POD samplers and hand wash samples; all were low with most samples for each analyte being below the limit of the detection with the exception of phenanthrene and pyrene. The geometric mean concentrations for phenanthrene and pyrene were 0.69 ng/cm^2 and 0.30 ng/cm^2 respectively on the polypropylene layer of the POD samplers and 1.37 ng/cm^2 and 0.29 ng/cm^2 respectively in the hand wash samples. Consistent with Boffetta et al. described above, Cavallari et al. showed that increasing frequency of glove use was associated with significant reductions for hand wash and POD phenanthrene and pyrene. Predictive models showed that the combined effect of substituting biodiesel for diesel oil as a cleaning agent, frequent glove use, and reducing the HMA application temperature may reduce dermal exposures by 76–86%.

6.3.4. Urinary biomarkers of polycyclic aromatic compound exposure

Biological markers (biomarkers) have been used to assess exposure to PACs or PAHs during occupational exposure to bitumen emissions. Although biomonitoring of exposure is a long-standing practice, complications arise due to confounders from diet and other sources on the job site. Also, when the concentrations of the pre- and post-shift samples differ by less than a factor or 10, interpretation of the results is sometimes difficult.

In a study with volunteers exposed to bitumen emissions in an exposure chamber, Knecht et al. measured dermal uptake by monitoring urinary PAH-metabolites in volunteers exposed with and without a fresh air supplied respirator. Urinary hydroxypyrene, hydroxy-chrysene and hydroxy-phenanthrene were used as indicators of total absorbed dose. Based on this controlled laboratory experiment, it was concluded that the contribution of dose via the respiratory and dermal routes were approximately equal with 57% of the dose of pyrene and chrysene being absorbed through the skin and 50% of the phenanthrene absorbed by that route.[90]

These studies and others are described in more detail by van Rooij et al.[91] in “Review of Skin Permeation Hazards of Bitumen Fumes.” The authors concluded that “the methods for the determination of the actual dose rate due to dermal exposure of workers are not yet validated. Aspects such as (i) transfer rate to the pseudo skin pads or patches compared to real skin transfer are not known, (ii) the estimation of the total body dose is not standardised, (iii) data on permeation coefficients of carcinogenic compounds through human and animal skin are limited, and (iv) it is not known which part of the 8-hour contamination on workers skin becomes available in target tissues.”

Pesch et al.[92] investigated biomarkers of bitumen exposure in a cross-shift study in 317 exposed and 117 non-exposed workers. Post shift concentrations, after statistical modelling, showed a slight increase in 1- hydroxypyrene by a factor of 1.02 per 1 mg/m^3 bitumen (P = 0.02) and 1.04 for 1- and 2-hydroxynaphthalene (P < 0.001).

McClean et al.[93] studied personal air (n=144), hand wash (n=144), and urine samples (n=480) collected from 12 paving workers over three consecutive workdays during four workweeks. Results provide evidence that PAHs in air are dermally absorbed. This study also showed that reducing the application temperature of asphalt mix holds great promise for reducing PAH exposure among paving workers. Additional reductions may be achieved by requiring increased dermal coverage of workers and by substituting biodiesel for diesel oil as a cleaning agent.

6.4. Refinery and terminal exposure data

Workplace exposure measurements are susceptible to variability, in magnitude and constituent, from a variety of potential confounders, some of which may be introduced in the manufacturing process, others through application technologies and others which may pre-exist in the ambient environment. As a result, reported values of exposures over time, between studies, and between the various countries must be considered carefully before use in development of dose-response relationships or potential risk estimates.

A combination of published and unpublished refinery and terminal exposure data are presented in Appendix 5. Exposure data during handling and application of bituminous materials can be found in other documents[80] [74] [3] [94] [53] [95] [96] devoted to the specific sectors of paving, roofing and mastic asphalt.

However, a comparison, using summary information, is provided in Table 3. For each sector the worker breathing zone exposure data were summarised to provide inhalation information for TP, BSF, and TOM. Summary statistics were weighted by number of subjects within each exposure study. Table 3 includes refinery sector data shown in Appendix 5 summarised using this approach.

Roofing manufacturing summary data include roofing asphalt manufacturing in co-located facilities and represents seven studies.[97] [78] [87] [98] [99] [37] [95]

Table 3 also provides inhalation data for the mastic sector including BSF and TP results from Brandt et al.[37] and use methods similar to the other data presented. A different method is used by BGIA in Europe (BGIA sampling system GSP (BG-Institute for Occupational Safety and Health – BGIA) with FTIR analysis).[53] Rühl et al., using this BGIA method, provide directly comparable vapour plus aerosol data on the following sectors: rolled paving GM =1.99 mg/m^3 (n=298), roofing application GM = 2.51 mg/m^3 (n=182), and mastic GM = 7.36 mg/m^3 (n=608).

Table 3. Summary Estimates for Various Industry Sectors based on Weighted Averages of the Arithmetic Mean.

	Total Particulates			
	Arithmetic Mean (AM) TP mg/m³	Geometric Mean (GM) TP mg/m³	No. of workers represented AM/GM	Studies Represented AM (GM)
Refinery/Terminal[a]	**0.46**	**0.18**	*204*	*19*
Roofing - Manufacturing[b]	**0.84**	**0.62**	*686/821*	*3[c] (5)[d]*
Paving - Hot Application	**1.45**	**0.32**	*1896/2251*	*11g (13)h*
Roofing - Hot Application	**1.34**	**0.89**	*299*	*14[l]*
Mastic	**20.7**	**na**	*12*	*3[m]*
	Benzene Soluble Fraction			
	Arithmetic Mean BSF mg/m³	Geometric Mean BSF mg/m³	No. of workers represented AM/GM	Studies Represented AM (GM)
Refinery/Terminal[a]	**0.28**	**0.10**	*197*	*16*
Roofing - Manufacturing[b]	**0.22**	**0.11**	*882/1017*	*4[c] (5)[d]*
Paving - Hot Application	**0.16**	**0.09**	*749/962*	*9[i] (13)[h]*
Roofing - Hot Application	**0.77**	**0.46**	*338*	*18[m]*
Mastic	**12.8**	**na**	*12*	*3[m]*
	Total Organic Matter			
	Arithmetic Mean TOM mg/m³	Geometric Mean TOM mg/m³	No. of workers represented AM/GM	Studies Represented AM (GM)
Refinery/Terminal[a]	**2.43**	**1.31**	*32*	*2*
Roofing - Manufacturing[b]	**1.50**	**0.82**	*151/228*	*1[e](2)[f]*
Paving - Hot Application	**1.10**	**0.72**	*335/415*	*6[j] (5)[k]*
Roofing - Hot Application	**1.47**	**0.71**	*115*	*4[n]*
Mastic	**Range = 0.13 – 77***		**608**	*1[o]*

*vapour and aerosols (v + a) using the BGIA sampling system GSP (BG-Institute for Occupational Safety and Health – BGIA) with FTIR analysis.

Summary statistics weighted by number of subjects within each exposure study. [a] References found in Appendix 5; [b] Includes roofing asphalt manufacturing in co-located facilities; c (97); (78); (87); d (97); (78); (87); (98); (99); e (78); f (78); (99); g (87); (98); (37); (69); (77); (76); (100); (101); (102); (67); (103); h (78); (87); (98); (69); (77); (76); (100); (101); (102); (67); (103); (80); (74); i (97); (78); (69); (77); (76); (101); (102); (67); (103); j (78); (77); (76); (67); (80); (95); k (78); (99); (77); (76); (67); l (96); m (37); n (53)

7. Health and Safety

No health or safety impacts have been identified from exposure to the final, in-service, use of bitumen products, e.g., roads, roofing, etc. In addition, the properties of bitumen do not meet the criteria for classification as hazardous to health, e.g. under EU regulation on Classification, Labelling & Packaging (CLP) (Concawe report 10/14) in Europe. However, occupational exposure to bitumen and bitumen emissions may be associated with potential hazards, as identified below.

7.1. Occupational Hazards

7.1.1. Burns

Contact with hot bitumen can cause severe burns to the eyes and skin, even in small quantities. Full covering clothing (i.e. long pants and long sleeved shirts) and other Personal Protective Equipment such as heat resistant gloves, safety glasses, and face shields can help to prevent burns during handling. For additional information on preventing burns, consult VA-26: Safe Handling of Hot Asphalt. First Aid guidance(104) is available through Asphalt Institute & Eurobitume.

7.1.2. Irritation

A number of components of emissions from hot bitumen, including Hydrogen Sulphide (H_2S), have been associated with eye, skin, and/or respiratory irritation, as summarised by NIOSH and ACGIH.(94)(105) Heating bitumen increases emissions that can be inhaled or come into contact with the skin. Keeping the temperature of heated bitumen as low as possible is an important way to reduce the generation of bitumen emissions, and therefore lower the potential for irritation. Additional engineering controls, work practices.

7.1.3. Cancer

As reviewed in the prior sections, crude oil contains polycyclic aromatic hydrocarbons, some of which are carcinogenic. While most PAHs segregate into other petroleum streams during the refining processes, relatively low concentrations of residual PAHs occur in bitumens. As a result, bitumens have been studied for cancer potential.

Published data suggests that bitumen does not present a cancer hazard.(106) The low levels of PAHs in bitumen are not readily bioavailable and human exposure to PAHs from handling of the bitumen substance is very low. The principal occupational exposure during handling and application of hot bitumen is to its emissions.

A recent review of cancer potential to humans from occupational exposure to bitumen & bitumen emissions was conducted by the International Agency for Research on Cancer (IARC) in 2011 and published in 2013.(107) The overall evaluation of cancer potential to humans was based on consideration of cancer findings in humans, cancer studies in experimental animals and mechanistic and other relevant data. In that review, IARC noted the potential influence of solvents and temperature on carcinogenic potential.

IARC observed that there were no consistent increases in cancer in either the occupation of paving or in animal studies with paving bitumens, or emissions (see also Clark et al., 2011). Limited evidence was observed for cancer associated with the occupations of roofing and mastic asphalt. No animal data are available for mastic asphalts. Animal studies of Asphalt Fume Condensate (AFC) from a specific type of roofing bitumen, Type III BURA, resulted in evidence of cancer potential to mouse skin.(108) (109)

The IARC evaluation of the “mechanistic and other relevant data” concluded that there was ‘strong’ evidence for a mechanism for cancer in the occupation of paving, which was of sufficient importance to elevate the overall conclusion for paving from Category 3 to Category 2B. The mechanistic evidence for roofing and mastic sectors was considered only weak and hence this had no bearing on the final evaluations for these sectors. The overall conclusions are summarised in Table 4.

Table 4: Summary of IARC Evaluation(107)

Occupational Sector	Bitumen Type/ Class	Overall Evaluation
Paving	Straight-run bitumens	Occupational exposures to straight-run bitumens and their emissions during road paving are possibly carcinogenic to humans (Group 2B)
Roofing	Oxidised bitumens	Occupational exposures to oxidised bitumens and their emissions during roofing are probably carcinogenic to humans (Group 2A)
Mastic	Hard bitumens	Occupational exposures to hard bitumens and their emissions during mastic-asphalt work are possibly carcinogenic to humans (Group 2B)

7.1.4. Hydrogen sulphide (H_2S)

Hydrogen sulphide is a hazardous gas that may be present in the vapour space of tanks, trucks, rail cars, and barge compartments that contain (or have contained) hot bitumen. Many factors influence the presence and/or release of H_2S in bitumen, including temperature, agitation, crude oil source, blend components, and additives (e.g. H_2S scavengers). Changing storage and handling conditions may increase or reduce release of H_2S. When inhaled H_2S can impact the nervous, cardiovascular, and respiratory systems. Effects are highly dependent upon the concentration of the gas and depend less on total time of exposure. Effects may range from offensive odour, eye, and respiratory tract irritation at lower levels to rapid unconsciousness and death at higher concentrations. H_2S usually produces no permanent effect as long as concentration levels remain low (that is, within exposure limits). H_2S effects at these levels are not cumulative and will not build up in the body (citation required). For more information on the management of H_2S risks in bitumen facilities, consult IS-225: "Management Practices for Asphalt Facility Control of Hydrogen Sulphide Exposure" and “Potential Risks of Hydrogen Sulphide (Gas) through the Bitumen Manufacture and Delivery Process” available through Eurobitume.

7.1.5. Naphthalene

Naphthalene is found at low concentrations in bitumen emissions. Naphthalene has been identified as a carcinogen under EU CLP and by U.S. regulators. These conclusions were largely based on evidence of tumors in studies conducted in rats and mice. Significant additional research by the Naphthalene Research Council, including 28 peer-reviewed publications, indicates that some of the cancer data is not relevant to humans and that potency estimates are not valid. Additional research is ongoing and a final US EPA IRIS (Integrated Risk Information System) review is expected by the end of 2016.

7.2. Hazard communication of additives and modifiers

Manufacturers of bitumen products should comply with hazard classification and communication regulations for the product and, as appropriate, identify and hazardous additives used in the product, in addition to any hazards or risks arising from the non-bituminous component(s). If appropriate, any risk transferred to the bitumen product should be identified. The non-bitumen blend components identified above are added at varying dosage levels depending on the additive. Composition and potential exposure downstream of manufacturing operations is addressed in documents by application sectors for paving, roofing and mastic asphalt.[1] [2] [3]

7.3. Classification and Labelling (C&L)

Bitumens are considered by industry to be safe in their intended use when used under the appropriate safe handling guidelines. Potential hazards associated with bitumen use are not solely derived from intrinsic properties of the bitumen itself, but rather reflect use conditions. In Europe Concawe publishes recommendations for classification and labelling of petroleum substances. According to these recommendations bitumen is not classified as hazardous to health or the environment.[110] Rather, appropriate risk management measures and warnings associated with occupational exposure have been recommended, e.g. by Concawe. Similar broad industry-based health recommendations have not been specifically made in North America, where C&L decisions are solely made on a case-by-case basis by manufacturers and suppliers under U.S. OSHA and Canadian WHMIS regulations, but general practices are similar. C&L in North America is, at the time of publication, transitioning to the Global Harmonised System (GHS) of Classification and Labelling of Chemicals, a system which is already in use in Europe and applied to petroleum streams by Concawe.[111] General industry guidance for the application of GHS to complex petroleum-derived substances such as bitumen can be found linked to the United Nations GHS site at: http://www.unece.org/trans/danger/publi/ghs/guidance.html.

8. Sustainability

Bitumen, in the form of commercial products manufactured with bitumen as a component, is one of the most recycled materials in the world. Beginning in the 1970’s the recycling of asphalt pavements (typically referred to as RAP) into new asphalt mixtures was initiated. Today virtually no bituminous pavements that are removed are landfilled. In the mid 2000’s experimentation into the use of recycling post-consumer shingles, and other bituminous roofing materials, (often referred to as RAS) into bituminous pavements started. Because of the high percentage of bitumen in shingles (20% and higher), the re-use of shingles has become very popular in the asphalt paving industry. However, because the bitumen used in shingles is much stiffer than most typical paving grade bitumen there is a need to use some type of softening agent when high levels of shingles are used asphalt mixtures.

A spinoff from this need has been the growing development of softening agents based on seed oil and other plant based chemicals which themselves are sustainable products. The growing use of warm mix technologies which reduce the stiffening of the bitumen in asphalt mixtures at the time of production is also helping to enable the use of higher levels of recycled bitumen materials into new pavements. There is no shortage of research being conducted around the world into additives and processing technologies that will enable increased levels of recycled bitumen containing materials into new asphalt pavements.

APPENDIX 1. List of Abbreviations and 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)

mg SI notation for milligram

µg SI notation for microgram

m³ SI notation for cubic metre

AASHTO American Association of State Highway and Transportation Officials

ACGIH American Conference of Governmental Industrial Hygienists

ASTM, ASTM INTERNATIONAL Formerly known as American Society of Testing and Materials, as of 2001 name changed to ASTM International. An organisation that develops and delivers voluntary consensus standards.

CAS # Chemical Abstract Services Registry Number

CEN Comité Europeen de Normalisation

CLP Classification Labeling and Packaging

Concawe Concawe is an organisation of European Oil Companies for Environment, Health and Safety. The acronym stands for CONservation of Clean Air and Water in Europe

DHHS Department of Health & Human Services (A US Government agency)

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.

EVT Equi-Viscous Temperature

GHS Globally Harmonised System

NIOSH National Institute of Occupational Safety and Health

OEL Occupational Exposure Limit

OSHA Occupational Safety and Health Administration

PAH/PAC Polycyclic Aromatic Hydrocarbon, Polycyclic Aromatic Compounds

PMB/PMA Polymer-Modified Bitumen/Asphalt

PNA Polynuclear Aromatic

PPA Polyphosphoric Acid

PPE Personal Protective Equipment

RAP Reclaimed Asphalt Pavement

RAS Reclaimed Asphalt Shingles

REACH Registration, Evaluation Authorisation of Chemicals (European Chemicals Regulation EC No 1907/20

REOB Re-refined Engine Oil Bottoms

REL Recommended Exposure Limit

RLOB Re-refined Lube-Oil Bottoms

TLV Threshold Limit Value

TSCA Toxic Substances Control Act

VTAE Vacuum Tower Asphalt Extender

Glossary

This glossary represents a consolidated collection of terms used in the bitumen industry. Not all of the terms listed below are used in this document, but are common expressions used in the bitumen supply chain.

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 functionally the same as straight-run bitumens. Air rectified bitumens are used in paving applications as well as selected roofing applications, such as shingle saturants and Type 1 Built Up Roofing Asphalt (BURA),and also for some industrial applications. **AIR-RECTIFIED BITUMENS** have a **PENETRATION INDEX** (PI) <+2.0.

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**. Use of the term **ASPHALT CEMENT** is decreasing in use in favor of **ASPHALT BINDER**. Historically **ASPHALT CEMENT** referred to bitumen products that contained no modifiers or additives.

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 MASTIC
A term of art in asphalt mixture technology referring to the combination of bitumen and the fine mineral portion of the aggregate generally comprised of mineral matter finer than 150 µm.

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 RESIDUUM
Residuum of **ATMOSPHERIC DISTILLATION** of **CRUDE OIL**.

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 (BBR)
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**.

BINDER REPLACMENT RATIO, BINDER REPLACEMENT %
When **RECLAIMED ASPHALT PAVEMENT** (RAP) or **RECLAIMED ASPHALT SHINGLE** (RAS) is added to a bituminous paving mixture the ratio of the amount of bitumen contributed by the RAP/RAS to the total bitumen content of bituminous paving mixture is referred to as the **BINDER REPLACEMENT RATIO**. Older terminology referred to the ratio as a percent and therefore **BINDER REPLACMENT** % can still be found in the literature.

BIO-BINDERS / BIO BITUMENS, BIO-FLUXED BITUMEN
A general term applied to a variety of petroleum bitumen alternatives produced solely from non-petroleum, renewable chemical sources or from blends of non-petroleum, renewable chemical sources and conventional petroleum bitumen. These non-petroleum sources include but are not limited to vegetable oils (generally reacted to substantially remove fatty acid functionality), tall oil fatty acid derivatives, tall oil rosin acid derivatives, lignin, manure, cashew nut shell oil (urushiol), vegetable based waxes, and many others.

BIO REJUVENATORS
Term applied to non-petroleum-derived, renewable and generally vegetable or tall-oil based softening agents added to petroleum based bitumen to improve the performance of the blended product with RAP and/or RAS containing asphalt mixtures.

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 EMISSIONS
The complex mixture of aerosols, vapours and gases from heated **BITUMEN** and products containing bitumen; although the term “**BITUMEN FUME**” is often used in reference to total emissions, technically bitumen fume does not include gases (i.e. solid particulate matter, aerosols and vapour).

BITUMEN EMISSION (FUME) CONDENSATE see also **ASPHALT FUME CONDENSATE**
The condensate of emissions from heated **BITUMEN**; the chemical composition may vary with the temperature and type of bitumen. It typically has a boiling range similar to kerosene.

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 EXTRACT
The fraction of **BITUMEN** that is soluble in organic solvents, such as benzene, toluene, carbon disulphide, or dimethyl sulphoxide.

BITUMEN FUME
The complex mixture of vapors and aerosols emitted 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 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 lamp-black, 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**. In North America a **PRIMER** is a spray coating to bond and underlying layer to the first layer of **HOT MIX ASPHALT**. As such it can be a **BITUMEN CUTBACK** or **BITUMEN EMULSION**.

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

BITUMEN VAPOUR
Refers to vapours which can include gases from heated **BITUMEN**.

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).

BLOWING STILL
(Also known as **OXIDISER**, Bitumen Blowing Unit, or Bitumen Oxidation Unit.) Equipment used to oxidise **BITUMEN**.

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

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)
OXIDISED BITUMEN used in the construction of low slope built up roofing (**BUR**) systems; specification defined by ASTM D312.

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 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**

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** and/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)

COLD IN-PLACE RECYCLING (CIR)
Utilisation of an integrated system to grind or mill existing bituminous pavement to a size generally smaller than 37.5 mm and incorporate new **BITUMEN** with an integrated mixing system into the reclaimed material followed by spreading or using an integrated paving machine to produce a road surface which is then compacted to a target density. The new **BITUMEN** is in the form of a **BITUMEN EMULSION** or a foamed bitumen.

COLLOID MILL
High-speed shearing device 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 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 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 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 a significant proportion of the dispersion medium for the **ASPHALTENES** and adsorbed resins in **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 diameter by 1 mm 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**

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**.

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 between aggregate particles.

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.

FLASH POINT
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 ASTMD92 for Open Cup Flashpoint and EN ISO 2719 or ASTMD93 for Closed Cup Flashpoint.

FLEXIBLE PAVEMENTS
Road surfacings made from layers of **ASPHALT** mixtures.

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 straight-run bitumen 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; Relatively involatile fluid (oil) used in the manufacture of **FLUXED BITUMEN**.

FLUX OILS (PETROLEUM)
Relatively non-volatile 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 **KEROSENE** and lubricating oil.

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

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

GROUND TIRE RUBBER (GTR) MODIFIED BITUMEN
BITUMEN to which rubber reclaimed from scrap tyres and ground to various mesh sizes has been added. The tyre rubber mesh size various depending on the specific processing method being employed. Mesh size used can be as large as 20 mesh (0.841 mm) and as small as GTR finer than 80 mesh (0.177 mm).

HARD BITUMEN
A rheologically stiff 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**.

HEAT WELDED 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
Site workers that perform miscellaneous tasks on work sites.

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, also part of EN 12607-1 & -2.

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).

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.

MILLING or MILLING MACHINE
Milling is the term applied to the use of machine comprising a large rotating mandrel with carbide steel teeth attached to the surface of the mandrel capable removing existing **ASPHALT** from the road surface. This milled **ASPHALT** is fed on an integrated conveyer to trucks which haul the milled **ASPHALT** to a central location where it is stockpiled and ultimately incorporated as RAP into a new **ASPHALT** pavement.

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.

THE MULTIPLE STRESS CREEP RECOVERY (MSCR) PROCEDURE
A rheological test performed on a **DYNAMIC SHEAR RHEOMETER** (DSR) to determine the non- recoverable compliance of a **BITUMEN**. **NON-RECOVERED COMPLIANCE** of a **BITUMEN** has been shown to correlate to the **BITUMEN'S** contribution to the rutting resistance of an **ASPHALT MIXTURE**.

NATURAL ASPHALT
Naturally-occurring mixture of **BITUMENS** and mineral matter formed by oil seepages in the earth's crust then evaporating through geological forces. Natural asphalts include Trinidad Lake, Rock, Gilsonite, Selenice and others.

NON-RECOVERED COMPLIANCE
A measure of the resistance to permanent deformation that a bitumen in an asphalt mixture contributes to the pavement. Low values of non-recovered compliance, for example values less than 1 kPa-1 or less than 0.5 kPa-1, at a given pavement temperature are very resistant to permanent deformation under heavy or extreme loading conditions.

OIL (PETROLEUM) VACUUM DISTILLATION BOTTOMS, USED (CAS RN 129893-17-0)
A very complex combination of high molecular weight hydrocarbon consisting mostly of spent polymers and organometallic based additives which have been removed as a non-volatile residue from waste lubricating oils. This material consists primarily of hydrocarbons with a carbon number greater than 25, and with high carbon to hydrogen ratios. This material will contain metals such as zinc, calcium, sodium and magnesium. Numerous trade names exist for this material including **RE-REFINED ENGINE OIL BOTTOMS** and, **VACUUM TOWER ASPHALT EXTENDER**.

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 fiber 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 subgroup of the larger family of chemicals - Polycyclic Aromatic Compounds (PAC). PAC can include atoms other than carbon and hydrogen, such as nitrogen, oxygen or sulphur.

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 EN 1426 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**.
A **PENETRATION INDEX** of zero is attributed to a bitumen with a **PENETRATION** at 25°C (77°F) of 200 x 0.1mm and a **SOFTENING POINT** of 40°C (104°F).
The **PENETRATION INDEX** is calculated as follows (according to EN 12591);

$$I_{\mathrm{p}} = \frac{20 \times t_{\mathrm{RaB}} + 500 \times \lg P - 1952}{t_{\mathrm{RaB}} - 50 \times \lg P + 120}$$

PENETRATION TEST
Specification test to measure the hardness of **BITUMEN** under specified conditions. In which the indentation into a **BITUMEN** in tenths of a millimeter (0.1 mm) at 25°C (77°F) is measured using a standard needle with a loading of 100 grams and 5 seconds duration. Details of the test can be found in ASTM D5 and/or EN 1426 as well as other sources.

PERFORMANCE GRADED BINDERS
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 and conform to specifications as stipulated in ASTM D6373, AASHTO M320 and AASHTO M332

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 – 180°C (104 – 356°F). 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/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: $H_6P_4O_{13}$.
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.

RAKERMAN
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**.

RAP
Acronym for Reclaimed or Recycled Asphalt Pavement. In practice existing asphalt pavement is removed from the roadway and crushed to a useable dimensions (generally less than 25 mm) and incorporated at some percentage into a new paving material. Typically **RAP** has been added to bituminous paving mixtures in amounts equivalent to **BINDER REPLACEMENT RATIOS** of 0.10 to 0.25. Recently research has sought to find methods to increase this ratio to as much as 0.50.

RAS
Acronym for Reclaimed Asphalt Shingles. In practice post-consumer waste shingles are ground to a size generally smaller than 12.5 mm which is then incorporated in bituminous paving mixtures. Typically 3% to 6% RAS is added to a bituminous mixture resulting in a **BINDER REPLACEMENT RATIO** of approximately 0.15 to 0.25.

RE-REFINED ENGINE OIL BOTTOMS (REOB)
See **OIL (PETROLEUM) VACUUM DISTILLATION BOTTOMS, USED**

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

REJUVENATOR
Term applied to any type of **FLUXING OIL** or softening agent added to a **BITUMEN** with the express intent of altering the rheological and compositional properties of aged **BITUMEN** that is incorporated into the **ASPHALT MIXTURE**. The aged Bitumen added to the asphalt mixture is generally incorporated through the addition of **RAP** and/or **RAS** materials. There is currently no consensus among bitumen technologists as to whether true rejuvenation of aged **BITUMEN** occurs or whether all such rejuvenators only function to soften the **BITUMEN** to which they are added and therefore reduce the overall stiffness of the total asphalt mixture.

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 RESIDUUM** 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, USA 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 75-85 minutes. See ASTM D2872, or EN 12607-1. The test was designed to simulate aging of the Bitumen through the Hot-Mix plant.

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, SATURATED 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.

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
Synonym for **AIR-RECTIFIED BITUMEN**

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 RESIDUUM** by solvent precipitation (usually with propane). 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 RESIDUUMS that have been subjected to **STEAM-STRIPPING**. Archaic term

STEAM STRIPPING
Injection of steam into a residuum 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
Similar to **STRAIGHT-RUN BITUMENS** and **STEAM-REFINED BITUMENS**

STRAIGHT-RUN BITUMENS
VACUUM RESIDUUMS 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.

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 %m of the original bitumen content.

SURFACE DRESSING (Synonym for **CHIP SEAL**)
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 waterproof a surface. It is normally covered with aggregate to provide friction to the roadway.

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.

TERMINAL BLENDED CRUMB RUBBER MODIFIED BITUMEN
Generally consists of blending ground tire rubber of a size range from 600μm to 177μm (30 to 80 mesh) with asphalt binder at temperatures ranging from 175 to 190°C (≈ 350 to 375°F) and allowing them to react for 60 (+) minutes prior to transfer to large storage tanks. Once mixed, the rubber modified asphalt is stored at elevated temperatures.

THERMALLY CRACKED BITUMENS
Also known as Residues (petroleum), thermal cracked, vacuum: **BITUMENS** produced by thermal cracking, followed by vacuum distillation.

THERMOPLASTIC POLYMER (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.

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 RESIDUUM** under vacuum.

VACUUM TOWER ASPHALT EXTENDER
Terminology endorsed by the National Oil Recyclers Association applied to Used Oil Vacuum Tower Distillation Bottoms and described by CAS# 128983-17-0. These materials have been added to **BITUMEN** to change the low temperature properties and to enhance the oxidation of some bitumen roofing products. Numerous other terms have been employed by the producers and users of this type of additive. When used in paving the material is added up to 10% to soften the BITUMEN for use with **RAP** or **RAS** or meet cold weather requirements. When used in **OXIDISED ASPHALT** it is added up to 6% as a paraffinic oil to increase penetration.

VACUUM RESIDUUM
Residue obtained by **VACUUM DISTILLATION**.

VISBREAKING
A relatively mild thermal cracking operation mainly used to reduce the viscosity and pour point of **VACUUM RESIDUUMS** for subsequent use in heavy fuel oils. The process converts a proportion of the residuum 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 utilise **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 or dense graded **HOT MIX ASPHALT** pavement. **WARM-MIX ASPHALTS** are produced and placed at temperatures typically 10 – 40°C (50 – 100°F) lower than conventional rolled or dense graded **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 aluminium 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 2. CAS and EINECS descriptions for commonly used bitumens

European and US Inventory Status: Commonly used bitumen streams.

		Regulatory Entities			
CAS Registry #		**EINECS #**	**REACH***	**TSCA**	**DSL/ NDSL**
8052-42-4	**Asphalt** A very complex combination of high molecular weight organic compounds containing a relatively high proportion of hydrocarbons having carbon numbers predominantly greater than C25 with high carbon-to-hydrogen ratios. It also contains small amounts of various metals such as nickel, iron, or vanadium. It is obtained as the non-volatile residue from distillation of crude oil or by separation as the raffinate from a residual oil in a deasphalting or decarbonization process.	232-490-9	R	Listed	DSL
64741-56-6	**Residues (petroleum), vacuum** A complex residuum from the vacuum distillation of the residuum from atmospheric distillation of crude oil. It consists of hydrocarbons having carbon numbers predominantly greater than C34 and boiling above approximately 495°C (923°F).	265-057-8	R	Listed	DSL
64742-85-4	**Residues (petroleum), hydrodesulfurized vacuum** A complex combination of hydrocarbons obtained by treating a vacuum residuum with hydrogen in the presence of a catalyst under conditions primarily to remove organic sulphur compounds. It consists of hydrocarbons having carbon numbers predominantly greater than C34 and boiling approximately above 495°C (923°F).	265-188-0	R	Listed	DSL
64742-93-4	**Asphalt, oxidized** A complex black solid obtained by blowing air through a heated residuum, or raffinate from a deasphalting process with or without a catalyst. The process is principally one of oxidative condensation which increases the molecular weight.	265-196-4	R	Listed	DSL
91995-23-2	**Asphaltenes (petroleum)** A complex combination of hydrocarbons obtained as a complex solid black product by the separation of petroleum residues by means of a special treatment of a light hydrocarbon cut. The carbon/hydrogen ratio is especially high. This product contains a low quantity of vanadium and nickel.	295-284-8	PR	Not Listed	Not Listed

92062-05-0	**Residues (petroleum), thermal cracked vacuum** A complex combination of hydrocarbons obtained from the vacuum distillation of the products from a thermal cracking process. It consists predominantly of hydrocarbons having carbon numbers predominantly greater than C34 and boiling above approximately 495°C (923°F).	295-518-9	R	Not Listed	Not Listed
94114-22-4	**Residues (petroleum), dewaxed heavy paraffinic, vacuum** A complex combination of hydrocarbons obtained as the residue from the molecular distillation of a dewaxed heavy paraffinic distillate. It consists of hydrocarbons having carbon numbers predominantly greater than C80 and boiling above approximately 450°C (842°F).	302-656-6	PR	Not Listed	Not Listed
100684-39-7	**Residues (petroleum), distn. residue hydrogenation** A complex combination of hydrocarbons obtained as a residue from the distillation of crude oil under vacuum. It consists predominantly of hydrocarbons having carbon numbers predominantly in the range above C50 and boiling in the range above approximately 360°C (680°F).	309-712-9	PR	Not Listed	Not Listed
100684-40-0	**Residues (petroleum), vacuum distn. residue hydrogenation** A complex combination of hydrocarbons obtained as a residue from the distillation of crude oil under vacuum. It consists predominantly of hydrocarbons having carbon numbers predominantly in the range above C50 and boiling in the range above approximately 500°C (932°F).	309-713-4	PR	Not Listed	Not Listed
64742-16-1	**Petroleum Resins** A complex combination of organic compounds, predominantly hydrocarbons, obtained as a fraction of the extract from solvent extraction of residuum. It consists predominantly of high molecular weight compounds with high carbon-to-hydrogen ratios.	N/A	NR	Listed	DSL
64742-07-0	**Raffinates (petroleum), residual oil decarbonization** A complex combination of hydrocarbons obtained as the solvent insoluble fraction from C5-C7 solvent decarbonization of a residual oil. It consists predominantly of aromatic hydrocarbons having carbon numbers predominantly higher than C34 and boiling above approximately 495°C (923°F).	N/A	NR	Listed	DSL

*R=Registered
PR=Preregistered
NR=No Registration for bitumen use

Health Classifications of Bitumen by Various Agencies and Authorities

Agency	Substance	Classification
American Conference of Governmental Industrial Hygienists	Asphalt (bitumen) fumes [8052-42-4]	A4 - Not Classifiable as a Human Carcinogen
International Agency for Research on Cancer (2013)	Occupational exposures to hard bitumens and their emissions during mastic- asphalt work Occupational exposures to oxidized bitumens and their emissions during roofing [64742-93-4] Occupational exposures to straight-run bitumens and their emissions during road paving [8052-42-4, 64741-56-6	Group 2B – Possibly Carcinogenic to Humans Group 2A – Probably Carcinogenic to Humans Group 2B – Possibly Carcinogenic to Humans
California Safe Drinking Water and Toxic Enforcement Act	Extracts of steam-refined and air-refined bitumen	Listed as carcinogen
European Union Classification (Annex VI of CLP-Regulation (EC) No 1272/2008	Bitumen Asphalt, Oxidized	Not classified Not classified
US National Institute for Occupational Safety and Health	Asphalt Fumes	NIOSH Carcinogen List
US National Toxicology Program	Asphalt Fumes	Evaluation deferred
Concawe (The Oil Companies' European Association for Environment, Health and Safety in Refining and Distribution): Report No. 8/12, 2012	Bitumen Asphalt, Oxidized	Not classified Not classified

APPENDIX 3. Occupational Exposure Limits for Bitumen Emission

Note: This table is believed to be accurate as of the date of publication (2015). Occupational Exposure Limits are updated periodically and the information should not be relied upon.

Asphalt (Petroleum Bitumen) air emissions – CAS number 8052-42-4				
Country	Limit, Units	Basis, Substance	Reference	Other information
ACGIH (USA)	0.5 mg/m^3	Time Weighted Average (TWA)	Threshold Limit Value (TLV) documentation	Benzene Soluble Inhalable Particulate. Note: This ACGIH OEL is not legally binding unless it has been formally adopted into National Legislation.
Australia	5 mg/m^3	8 hr - TWA	Safe Work Australia 2014	Fume
Belgium	5 mg/m^3	TWA, Asfalt (Petroleum) (Rook), Pétroles (Bitumes de) (Fumées)	2002 Moniteur Belge number 341, 25 October 2002. KB 11/3/2002	Total Particulate Matter (TPM)
Canada	0.5 mg/m^3 5 mg/m^3	8 hr - TWA	Ontario & British Columbia Provincial 2013 Quebec	Inhalable Fraction
China	5 mg/m^3	8 hr – TWA	GBZ 2.1 2007	Fume
Chile	4 mg/m^3	8 hr – TWA	Ministry of Health 2003	Fume
Denmark	1 mg/m^3	TWA Bitumenrøg	Arbejdstilsynet. Grænseværdier for stoffer og materialer. 2007	Defined as Cyclohexane Soluble Fraction of TPM
Finland	10 mg/m^3 5 mg/m^3	15 min 8h		
France	5 mg/m^3 0.5 mg/m^3	Similar to Total Organic Carbon method ACGIH method	INRS, CNAM-TS, coordination of occupational doctors	Stated as derived from EU Directive 98/24/CE Note: This is not a legally binding OEL in France. It has been recommended by the specified bodies for use in controlling workplace exposure to bitumen emissions.

Asphalt (Petroleum Bitumen) air emissions – CAS number 8052-42-4				
Greece	5 mg/m³	TWA Asphalt (Bitumen)	OELs (Decree No. 90/1999, as amended by Decree No. 339/2001, 9 October 2001, 2012	TPM
Indonesia	5 mg/m³	8 hr – TWA	Departemen Tenaga Kerja	Petroleum (Fumes)
Ireland	0.5 mg/m³ 10 mg/m³	TWA 15 minute STEL Asphalt, Petroleum Fumes	2011 Code of Practice for the Safety, Health & Welfare at Work [Chemical Agents] Regulations	(No method specified). Notice of intended change for STEL (to 1,5 mg/m3) given by HSA
Italy	0.5 mg/m³	TWA Asfalto (petrolio; Bitumen) fumi-come composti estraibili (solubili) in benzene dall'aereoso, frazione inalabile	OELs 2003	Benzene Soluble Inhalable Aerosol If no national limit exists value defaults to ACGIH
New Zealand	5 mg/m³			
Norway	5 mg/m³	TLV-TWA Asfalt (røyk)	Administrative normer for forurensning I arbeidsatmosfære 2003, No. 361	TPM
Poland	10 mg/m³ 5 mg/m³	15 min. Form: smoke 8 hr. Form: smoke	Asphalt fumes Minister of Labour and Social Policy (Poland, 11/2002).	
Portugal	0.5 mg/m³	Asfalto, fumos como aerossóis lolúveis em benzeno (VLE)	Segurança e Saúde no Trabalho Valores limite de exposiçao profissional a agentes químicos: NP 1796:2007 (Ed.4)	Inhalable Fraction, A4 basis for VLE: Eye irritation, Upper respiratory tract; Benzene Soluble Inhalable Aerosol
Slovenia	10 ml/m³	Vapour & aerosols	List of mandatory limit values for occupational exposure	Includes skin notation

Asphalt (Petroleum Bitumen) air emissions – CAS number 8052-42-4				
Spain	0.5 mg/m³	Daily exposure limit (VLA-ED)	Spain	
Singapore	5 mg/m³			
South Korea	0.5 mg/m³			
Switzerland	10 mg/m³	8 hr – TWA	SUVA 2013	Vapour and aerosols (skin notation)
UK	5 mg/m³ 10 mg/m³	TWA 10 min STEL Asphalt, Petroleum fumes	UK Health and Safety Executive. EH40/2011; Occupational Exposure Limits 2011	TPM
USA	5 mg/m³	15 min	NIOSH	Ceiling limit value (15 min) Measured as total particulates

TLV – Threshold Limit Value
TPM – Total Particulate Matter
TWA – Time Weighted Average
STEL – Short Term Exposure Limit
Non-regulated limit

United States State Plans' Enforcement Action - 1989 Air Contaminants

(Rev. 8/16/2013)

STATE PLAN *= public sector only	Reverted to 1971 PELS	Enforcing 1989 PELS/or See Comment	Comment
ALASKA		X	Adopted 8 AAC 61.1145, 2/15/2001, Register 157 instead of Appendix A of 29 C.F.R. 1926.55(a).
ARIZONA	X		
CALIFORNIA		X – See Comment	California updates their PELs through the rulemaking process. With the assistance of an advisory committee, and other agencies such as the Office of Environmental Health Hazard Assessment; Hazard Evaluation System and Information Service of the California Department of Health Services (HESIS); and Health Expert Advisory Committee (HEAC), the PELs are either updated or new ones are proposed.
CONNECTICUT*		X	
HAWAII		X - See Comment	Enforcing 1984 ACGIH PEL tables
ILLINOIS*		X	
INDIANA	X		
IOWA	X		
KENTUCKY	X		
MARYLAND	X		
MICHIGAN		X – See Comment	General industry only. Construction Safety enforcing 1970 ACGIH TLVs.
MINNESOTA		X	
NEVADA	X		
NEW JERSEY*	X - See Comment		Public sector only. Coverage excludes private sector health.
NEW MEXICO	X		

STATE PLAN *= public sector only	Reverted to 1971 PELS	Enforcing 1989 PELS/or See Comment	Comment
ALASKA		X	Adopted 8 AAC 61.1145, 2/15/2001, Register 157 instead of Appendix A of 29 C.F.R. 1926.55(a).
ARIZONA	X		
CALIFORNIA		X – See Comment	California updates their PELs through the rulemaking process. With the assistance of an advisory committee, and other agencies such as the Office of Environmental Health Hazard Assessment; Hazard Evaluation System and Information Service of the California Department of Health Services (HESIS); and Health Expert Advisory Committee (HEAC), the PELs are either updated or new ones are proposed.
CONNECTICUT*		X	
HAWAII		X - See Comment	Enforcing 1984 ACGIH PEL tables
ILLINOIS*		X	
INDIANA	X		
IOWA	X		
KENTUCKY	X		
MARYLAND	X		
MICHIGAN		X – See Comment	General industry only. Construction Safety enforcing 1970 ACGIH TLVs.
MINNESOTA		X	
NEVADA	X		
NEW JERSEY*	X - See Comment		Public sector only. Coverage excludes private sector health.
NEW MEXICO	X		
NEW YORK*		X	
NORTH CAROLINA	X		

STATE PLAN *= public sector only	Reverted to 1971 PELS	Enforcing 1989 PELS/or See Comment	Comment
OREGON		X –See Comment	Enforcing rules in effect in State pre-1989
PUERTO RICO	X		
SOUTH CAROLINA		X	
TENNESSEE		X	
UTAH	X		
VERMONT		X	
VIRGIN ISLANDS*	X—See Comment		Public sector only. Coverage excludes private sector health.
VIRGINIA	X		
WASHINGTON		X	
WYOMING	X		
TOTALS	14	13	

United States Department of Labor, & Occupational Safety and Health Administration. (Revised 8/16/2013). State Plans' Enforcement Action 1989 Air Contaminants. Table. Office of State Programs.

APPENDIX 4. Further reading on occupational exposure

Cancer Mortality Among European Asphalt Workers: Selected papers from a study of cancer risk in the European asphalt industry coordinated by the International Agency for Research on Cancer; *Am J Ind Med*, Vol 43, 1, 2003.

World Health Organisation "Concise International Chemical Assessment Document 59" 2005, available at http://www.who.int/ipcs/publications/cicad/cicad59_rev_1.pdf

Proceedings of The Health Effects of Occupational Exposure to Emissions from Asphalt/Bitumen Symposium, June 7-8, 2006, Dresden, Germany; *J Occup Environ Hyg.* Vol 4, Supplement 1, 2007.

A case-control study of lung cancer nested in a cohort of European asphalt workers. *Environ Health Perspect*. 2010 Oct; 118(10):1418-24.Epub 2010 Jun 9.

IARC Monograph Volume 103 on "Bitumens and Bitumen Emissions and some N- and S- Heterocyclic Polycyclic Aromatic Hydrocarbons" 2013, available at http://monographs.iarc.fr/ENG/Monographs/vol103/

APPENDIX 5. Summary of Refinery Sector Exposure Data

Occupation	Source of exposure	Number	Type	Range (mg/m^3)	Geo. Mean	Ari. mean	Ref	Source
General asphalt refinery workers	Vacuum distillation	4*	Total PAHs†	0.0047-0.016	0.0082	0.0095	NIOSH 1980[112]	NIOSH Hazard Review
General asphalt refinery workers	Asphalt processing (6 refineries)	14*	Total PAHs†	0.0015-0.031	0.067	0.010	NIOSH 1983[113]	NIOSH Hazard Review
General asphalt refinery workers	Deasphalting (1 refinery)	4*	Total PAHs†	0.0014-0.041	0.12	0.021		NIOSH Hazard Review
Assistant operator		3	Total PAHs†	0.0025-0.050	0.14	0.025		NIOSH Hazard Review
Bitumen loaders	Outdoor bitumen refinery unit (bitumen at 170 to 210°C [338 to 410°F])	‡	Benzene solubles	0.3-1.0	§	§	Claydon et al.1984[114]	NIOSH Hazard Review
		‡	Total particulates	0.1-1.4	§	§		NIOSH Hazard Review
Package fillers	Indoor area (bitumen at 220°C [428°F])	2	Total particulates	0.20-0.32	0.25	0.23	Brandt et al.1985[37]	NIOSH Hazard Review
Bitumen loaders	Outdoor bitumen refinery unit (bitumen at 170 to 210°C [338 to 410°F])	4	Total particulates	0.7-2.9	§	1.4		NIOSH Hazard Review
Operator		11	Total particulates	<0.03-8.2	0.17	0.88	Hicks 1995[87]	NIOSH Hazard Review
		11	Benzene solubles	0.034-1.9	0.14	0.42		NIOSH Hazard Review
Assistant operator	Asphalt refinery/ terminal (temperature of product at fume source ranged from 160 to 375°C [320 to 707°F])	9	Total particulates	<0.03-0.49	0.18	0.25	Hicks 1995[87]	NIOSH Hazard Review
		9	Benzene solubles	<0.066-0.32	0.11	0.13		NIOSH Hazard Review
		4	Total particulates	0.17-0.26	0.22	0.23		NIOSH Hazard Review
Lab technician		4	Benzene solubles	<0.062-0.43	0.15	0.21		NIOSH Hazard Review
Loader/pumper operator		10	Total particulates	<0.026-14	0.29	1.6		NIOSH Hazard Review
		10	Benzene solubles	0.038-13	0.29	1.6		NIOSH Hazard Review

Maintenance/ administration	Asphalt refinery/ terminal (temperature of product at fume source ranged from 160 to 375°C [320 to 707°F])	6	Total particulates	<0.032-0.77	0.17	0.29		NIOSH Hazard Review
		6	Benzene solubles	0.011-0.22	0.076	0.1		NIOSH Hazard Review
Utility worker		4	Total particulates	<0.024-0.062	0.039	0.043		NIOSH Hazard Review
		4	Benzene solubles	<0.054-1.1	0.3	0.49		NIOSH Hazard Review
General Refinery Workers			Hydroxypyrene				Boogaard et al 1995[115]	
Refinery Road tanker loading	Various Pen and oxidised grades (170-210°C [338-410°F])]	4	Total particulates	0.7-2.9			Brandt et al[37]	
General refinery Workers	Vacuum Distillation		Total PACs	1.8-19µg/m³			Futagaki et al 1981[116]	IARC mon #35 (same ref as NIOSH 1983)
Office worker	Bitumen Terminal	6	TPM BSM	0.04-0.29 0.03-0.08	0.08 0.04	0.12 0.04	Gamble[99]	
Lab Technician	Bitumen Terminal	7	TPM BSM	0.08-0.64 0.03-0.11	0.23 0.05	0.3 0.06		
Loader	Bitumen Terminal	14	TPM BSM	0.07-0.58 0.03-0.11	0.2 0.04	0.23 0.04		
Manager	Bitumen Terminal	4	TPM BSM	0.08-0.77 0.03-0.09	0.26 0.05	0.35 0.05		
Misc.	Bitumen Terminal	10	TPM BSM	0.03-2.51 0.03-0.2	0.19 0.09	0.43 0.2		
Loader/Pumper	Refinery/ Terminal	10	TPM BSM	<0.026-14 0.038-13	0.29 0.29	1.6 1.6	Hicks[87]	Further information to be found in full citation
Operator	Refinery/ terminal	11	TPM BSM	<0.03-8.2 0.034-1.9	0.17 0.14	0.88 0.42		
Driver / Loader	Truck loading gantry	3	TPM (UK HSE MDHS#70)	<0.01 – 0.3 mg/m³ 8hr TWA	NA	NA	Company Report	Unpublished UK production facility 1999
Plant operator	Bitumen unit during shutdown duties	1	TPM (UK HSE MDHS#70	0.1 mg/m³ 8hr TWA	NA	NA	Company Report	Unpublished UK production facility 1999
Driver / Loader	Truck loading gantry	6	TPM (UK HSE MDHS#14/2)	0.6 – 3.0 (mg/m³ 15 min STEL)	NA	NA	Company Report	Unpublished UK production facility 2001
Driver / Loader	Truck loading gantry (100/150pen)	1	TPM (UK HSE MDHS#14/2	0.66 (mg/m³ 15 min STEL)	NA	NA	Company Report	Unpublished UK production facility 2002

Driver / Loader	Truck loading gantry (40/60pen)	1	TPM (UK HSE MDHS#14/2	4.33 (mg/m^3 15 min STEL)	NA	NA	Company Report	Unpublished UK production facility 2002
Aid'operateur	Bitumen truck loading	4	TPM	0.09 - 0.27	0.17	0.18	Internal report OGMB 2001-107	Shell Global Solutions
Aid'operateur	Bitumen truck loading	4	BSF	0.1 - 0.2	0.10	0.12	Internal report OGMB 2001-107	Shell Global Solutions
Aid'operateur	Bitumen truck loading	4	SV	0.81 - 1.7	1.09	1.14	Internal report OGMB 2001-107	Shell Global Solutions
Truck driver	Bitumen truck loading	2	TPM	0.12 - 0.69	0.29	0.41	Internal report OGMB 2001-107	Shell Global Solutions
Truck driver	Bitumen truck loading	10	BSF	0.03 - 1.6	0.24	0.43	Internal report OGMB 2001-107	Shell Global Solutions
Truck driver	Bitumen truck loading	10	SV	0.09 - 1.4	0.38	0.53	Internal report OGMB 2001-107	Shell Global Solutions
Truck driver	Bitumen truck loading	6	16 EPA-PAHs		0.23 µg/m^3 8hr TWA	0.31 µg/m^3 8hr TWA	Personal Exposure to PAHs in the Refinery During Truck Loading of Bitumen	Deygout 2011[117]
Truck driver	Bitumen truck loading	6	Naphthalene	0.71 – 8.59 ng/m^3	1.89 ng/m^3	2.76 ng/m^3		
Truck driver	Bitumen truck loading	6	B[a]P	2 - 3 ng/m^3	2.2 ng/m^3	2.3 ng/m^3		
Truck driver	Bitumen truck loading	6	BSF	0.10 – 0.25 mg/m^3	0.13 mg/m^3	0.14 mg/m^3		
Truck driver	Bitumen truck loading	6	SV	0.55 1.45 mg/m^3	0.76 mg/m^3	0.80 mg/m^3		
Truck driver	Bitumen truck loading	6	THC	0.65 – 1.70 mg/m^3	0.89 mg/m^3	0.94 mg/m^3		
Plant Workers	Bitumen Refinery Plant Operations	82	BSF	0.01-0.26 mg/m3	0.03	0.05	HRG 2011-2013 Internal Report	Plant Workers
Plant Workers	Bitumen Refinery Plant Operations	82	TP	0.03-1.04 mg/m3	0.22	0.17	HRG 2011-2013 Internal Report	Plant Workers
Plant Workers	Bitumen Refinery Plant Operations	26	TOM	0.08-28.8 mg/m3	1.41	2.77	HRG 2011-2013 Internal Report	Plant Workers

TPM: Total Particulate Matters in mg/m^3
BSF: Benzene Soluble Fractions in mg/m^3
SV: Semi-Volatiles (gaseous fractions) in mg/m^3
Abbreviations: Ari. mean=arithmetic mean; Geo. mean=geometric mean.
* Area air samples. All remaining samples were personal-breathing-zone air samples.
† The sampling and analytical methods used for measuring PAH concentrations may vary between studies and results may not be directly comparable.
‡ Number of samples collected not available.
§ Information not provided.

NOTE: Sampling periods ranged from 6 to 8 hours. Results shown are time-weighted averages.

NOTE: Solvents such as cyclohexane and acetonitrile have been used in place of benzene to measure the soluble fraction of a particular matrix. Because the extraction ability of these solvents varies, results are not comparable.

NOTE: Detailed information on methods used to determine exposure can be found in the citations. It should be noted that the use of different analytical methods for determination of, e.g. Total Particulate Matter, or Benzene Soluble fraction, may give results that are not directly comparable.

REFERENCES

1. National Asphalt Paving Association, European Asphalt Pavement Association. The Asphalt Paving Industry: A Global Perspective. 3rd ed: National Asphalt Paving Association; 2011.

2. International Mastic Asphalt Association. The Mastic Asphalt Industry: A global perspective. Bern: IMAA; 2013. 30 p.

3. Asphalt Roofing Manufacturers Association, Bitumen Waterproofing Association, National Roofing Contractors Association, Roof Coatings Manufacturers Association. The Bitumen Roofing Industry - A Global Perspective. 2nd ed: Asphalt Roofing Manufacturers Association; 2011.

4. Hoiberg AJ. Bituminous materials: asphalts, tars, and pitches. New York: Interscience; 1964.

5. Puzinauskas VP, Corbett LW. Differences between petroleum asphalt, coal-tar pitch and road tar. College Park, Maryland: The Asphalt Institute, 1978 RR-78-1 Contract No.: RR-78-1.

6. Kriech AJ, Kurek JT, Osborn LV, Blackburn GR. Extraction and Analysis of Asphalt Pavement Core Samples: Detection of Coal Tar-Derived Species Using Chemical and Biological Methods. Polycyclic Aromatic Compounds. 1999;16(1-4):31-40.

7. Trinidad Lake Asphalt (TLA) [2/10/2015]. Available from: http://www.trinidadlakeasphalt.com/home/products/trinidad-lake-asphalt-tla.html.

8. Eurobitume (European Bitumen Association). Guidance on use of EINECS & CAS definitions for REACH registration. Eurobitume, January 2008.

9. Gary J, Handwerk G. Petroleum refining: Technology and economics. Volume 5. New York: Marcel Dekker, Inc.; 1975.

10. McKetta JJ. Petroleum processing handbook. New York: M. Dekker; 1992.

11. Zakar P. Bitumen. New York Chemical Pub. Co.; 1971. 205 p.

12. Jones DR. SHRP materials reference library: Asphalt cements: A concise data compilation. Strategic Highway Research Program, 1993 SHRP-A-645.

13. van Tine FM, Feintuch HM. FW Solvent Deasphalting. In: Meyers RA, editor. Handbook of Petroleum Refining Processes. 2nd ed: McGraw-Hill; 1997.

14. Choquet FS, Verhasselt AF. Natural and Accelerated Ageing Of Bitumens: Effects Of Asphaltene. In: Sharma M, Yen T, editors. Asphaltene Particles in Fossil Fuel Exploration, Recovery, Refining, and Production Processes: Springer US; 1994. p. 13-29.

15. Boduszynski M. Asphaltenes in petroleum asphalts: composition and formation. Advances in Chemistry Series. 1981;195(Chem. Asphaltenes):119-35.

16. Corbett LW. Reaction Variables in the Air Blowing of Asphalt. Industrial & Engineering Chemistry Process Design and Development. 1975;14(2):181-7.

17. Goppel JM, Knotnerus J. Fundamentals of Bitumen Blowing (Netherlands). 4th World Petroleum Congress; June 6-15; Rome, Italy: World Petroleum Congress; 1955.

18. Moschopedis SE, Speight JG. Oxidation of a bitumen. Fuel. 1975;54(3):210-2.

19. Bolliet C, Juery C, Thiebaut B. Impact of Oxidation Process on Polycyclic Aromatic Hydrocarbon (PAH) Content in Bitumen. JOccupEnvironHyg. 2013;10(8):435-45. doi: 10.1080/15459624.2013.801820.

20. Redelius PG. The structure of asphaltenes in bitumen. Road Materials and Pavement Design. 2006;7(sup1):143-62. doi: 10.1080/14680629.2006.9690062.

21. European Committee for Standardization. Bitumen And Bituminous Binders - Determination Of Needle Penetration. EN 1426: 2007.

22. European Committee for Standardization. Bitumen and bituminous binders - Specifications for paving grade bitumens. EN 12591: 2009.

23. Speight JG. The chemistry and technology of petroleum. 2nd ed: Marcel Dekker; 1991. 309- 56 & 443-9 p.

24. Petersen JC, Robertson RE, Branthaver JF, Harnsberger PM, Duvall JJ, Kim SS, et al. Binder Characterization and Evaluation. Volume 4: Test Methods. 1994 SHRP A 370.

25. Branthaver JF, Petersen JC, Robertson RE, Duvall JJ, Kim SS, Harnsberger PM, et al. Binder Characterization and Evaluation. Volume 2: Chemistry. 1993 SHRP A 368.

26. Read J, Whiteoak D. The Shell bitumen handbook. 5th ed. London: Thomas Telford; 2003. xii, 460 p. p.

27. Goodrich JL, Goodrich JE, Kari WJ. Asphalt composition tests: their application and relation to field performance. Transportation Research Record 1096,1986.

28. Erdman JG, Ramsey VG. Rates of oxidation of petroleum asphaltenes and other bitumens by alkaline permanganate. Geochimica et Cosmochimica Acta. 1961;25(3):175-88.

29. Moschopedis SE, Speight JG. Oxidation of petroleum fractions. Fuel. 1973;52(1):83.

30. Barbour R, Petersen J. Molecular interactions of asphalt. Infrared study of the hydrogen-bonding basicity of asphalt. Analytical Chemistry. 1974;46(2):273-7.

31. Campbell P, Wright J. Oxidation Products in Oxygen-Blown Kuwait Asphalt. Industrial & Engineering Chemistry Product Research and Development. 1966;5(4):319-23.

32. Smith C, Schuetz C, Hodgson R. Relationship between chemical structures and weatherability of coating asphalts as shown by infrared absorption spectroscopy. Industrial & Engineering Chemistry Product Research and Development. 1966;5(2):153-61.

33. Trumbore D, Osborn L, Blackburn G, Niebo R, Kriech A, Maxim LD. Effect of oxidation and extent of oxidation on biologically active PACs in asphalt products. Inhal Toxicol. 2011;23(12):745-61. doi: 10.3109/08958378.2011.608742.

34. Brandt HCA, de Groot PC. A laboratory rig for studying aspects of worker exposure to bitumen fumes. Am Ind Hyg Assoc J. 1999;60(2):182-90.

35. Pucknat AW. Health impacts of polynuclear aromatic hydrocarbons. Park Ridge, N.J.: Noyes Data Corp.; 1981.

36. Wallcave L, Garcia H, Feldman R, Lijinsky W, Shubik P. Skin tumorigenesis in mice by petroleum asphalts and coal-tar pitches of known polynuclear aromatic hydrocarbon content. Toxicol Appl Pharmacol. 1971;18(1):41-52.

37. Brandt H, de Groot P, Molyneux M, Tindle P. Sampling and analysis of bitumen fumes. The Annals of occupational hygiene. 1985;29(1):27-80.

38. Kriech AJ, Kurek JT, Osborn LV, Wissel HL, Sweeney BJ. Determination of polycyclic aromatic compounds in asphalt and in corresponding leachate water. Polycyclic Aromatic Compounds. 2002;22(3-4):517-35.

39. Brandt HCA, de Groot PC. Aqueous leaching of polycyclic aromatic hydrocarbons from bitumen and asphalt. Water Res. 2001;35(17):4200-7.

40. Heritage Research Group, Kriech AJ. Evaluation of Hot Mix Asphalt for Leachability. Asphalt Institute Report, 1990.

41. APA (Asphalt Pavement Alliance). Cleaner Water with Asphalt Pavements. Lanham, MD. 2011.

42. Warren R, Birch P. Heavy metal levels in atmospheric particulates, roadside dust and soil along a major urban highway. Science of the Total Environment. 1987;59:253-6.

43. Strecker EW, Driscoll ED, Shelley PE, Gaboury DR, Sartor JD. The US federal highway administrations receiving water impact methodology. Science of the Total Environment. 1990;93:489-98.

44. Pagotto C, Legret M, Le Cloirec P. Comparison of the hydraulic behaviour and the quality of highway runoff water according to the type of pavement. Water Research. 2000;34(18):4446-54.

45. Lau S-L, Han Y, Kang J-H, Kayhanian M, Stenstrom MK. Characteristics of highway stormwater runoff in Los Angeles: metals and polycyclic aromatic hydrocarbons. Water Environment Research. 2009;81(3):308-18.

46. Cooper SD, Kratz KW, Forrester G, Wiseman S. The Impact of Runoff from Asphaltic Products on Stream Communities in California. Sacramento, CA: California Department of Transportation, 1996 October. Report No.: FHWA/CA/TL-96-24.

47. Harrington-Hughes K. Primer: Environmental Impact of Construction and Repair Materials on Surface and Ground Waters. Transportation Research Board, 2000 NCHRP Report 443.

48. Winters N, Graunke K. Roofing Materials Assessment: Investigation of Toxic Chemicals in Roof Runoff. Publication No 14-03-003. Olympia, WA: Washington State Department of Ecology; 2014.

49. Nelson PO, Huber WC, Eldin NN, Williamson KJ. Environmental impact of construction and repair materials on surface and ground waters : summary of methodology, laboratory results, and model development. Washington, D.C.: National Cooperative Highway Research Program, 2001 NCHRP Report 448.

50. National Sanitation Foundation. NSF Product and Service Listings: NSF/ANSI 61 - Drinking Water System Components - Health Effects [2/12/2015]. Available from: http://info.nsf.org/Certified/PwsComponents/Listings.asp?TradeName=asph&StandardExt=&MaterialType=&ProductType=&PlantState=&PlantCountry=&PlantRegion=&Standard=061.

51. Eurobitume (European Bitumen Association). Bitumen as a component of construction products in contact with drinking water: Bitumen Leaching study results. June 2008.

52. Mahler BJ, Van Metre P. Coal-tar-based pavement sealcoat, polycyclic aromatic hydrocarbons (PAHs), and environmental health: U.S. Geological Survey Fact Sheet 2011–3010: US Department of the Interior, US Geological Survey; 2011.

53. Ruhl R, Musanke U, Kolmsee K, Priess R, Zoubek G, Breuer D. Vapours and Aerosols of Bitumen: Exposure Data obtained by the German Bitumen Forum. Annals of Occupational Hygiene. 2006;50(5):459-68.

54. Pohlmann G, Preiss A, Koch W, Kock H, Elend M, Raabe M. Collection, validation and generation of bitumen fumes for inhalation studies in rats Part 3: Regeneration of bitumen fumes, inhalation setup, validation. AnnOccup Hyg. 2006;50(8):813-9.

55. Kriech AJ, Emmel C, Osborn LV, Breuer D, Redman AP, Hoeber D, et al. Side-by-side comparison of field monitoring methods for hot bitumen emission exposures: the German IFA Method 6305, U.S. NIOSH Method 5042, and the Total Organic Matter Method. JOccupEnvironHyg. 2010;7(12):712-25.

56. Eurobitume (European Bitumen Association), Heritage Research Group, Kriech AJ. Comparison of straight run vacuum distilled bitumen and semi-blown bitumen. Eurobitume (European Bitumen Association), 2006 Report.

57. Preiss A, Koch W, Kock H, Elend M, Raabe M, Pohlmann G. Collection, Validation and Generation of Bitumen Fumes for Inhalation Studies in Rats Part 1: Workplace Samples and Validation Criteria. Annals of Occupational Hygiene. 2006;50(8):789-804.

58. Law BF, Stone S, Frazer D, Siegel PD. Characterization of laboratory simulated road paving- like asphalt by high-performance liquid chromatography and gas chromatography-mass spectrometry. Journal of Occupational and Environmental Hygiene. 2006;3(7):343-50. doi: 10.1080/15459620600732795.

59. Gaudefroy V, Viranaiken V, Paranhos R, Jullien A, de La Roche C. Laboratory assessment of fumes generated by bituminous mixtures and bitumen. Road Materials and Pavement Design. 2010;11(1):83-100.

60. Eurobitume (European Bitumen Association), Heritage Research Group, Kriech AJ. Bitumen Fume Composition as A Function of Binder Temperature - Physical and Chemical Analysis of Binder Fumes At Various Relevant Temperatures Using Two Different Laboratory Fume Generation Techniques. 2006 Report.

61. Burstyn I, Boffetta P, Kauppinen T, Heikkila P, Svane O, Partanen T, et al. Estimating exposures in the asphalt industry for an international epidemiological cohort study of cancer risk. Am J Ind Med. 2003;43(1):3-17.

62. Fayerweather WE, Trumbore DC, Johnson KA, Niebo RW, Maxim LD. Quantitative exposure matrix for asphalt fume, total particulate matter, and respirable crystalline silica among roofing and asphalt manufacturing workers. Inhalation Toxicology. 2011;23(11):668-79. doi: doi:10.3109/08958378.2011.604107.

63. Ekstrom L, Kriech A, Bowen C, Johnson S, Breuer D. International studies to compare methods for personal sampling of bitumen fumes. Journal of Environmental Monitoring. 2001;3(5):439-45.

64. McDermott HJ, Ness SA. Air monitoring for toxic exposures. 2nd ed. Hoboken, N.J.: Wiley-Interscience; 2004.

65. Levin JO, Jarvholm B. Asphalt fumes: exposure to PAH and amines. Am J Ind Med. 1999;Suppl 1:147-8.

66. Brandt HCA, Watson WP. Monitoring human occupational and environmental exposures to polycyclic aromatic compounds. Annals of Occupational Hygiene. 2003;47(5):349-78.

67. Kriech AJ, Kurek JT, Wissel HL, Osborn LV, Blackburn GR. Evaluation of worker exposure to asphalt paving fumes using traditional and nontraditional techniques. Am Ind Hyg Assoc J. 2002;63(5):628-35.

68. Cavallari JM, Osborn LV, Snawder JE, Kriech AJ, Olsen LD, Herrick RF, et al. Predictors of airborne exposures to polycyclic aromatic compounds and total organic matter among hot-mix asphalt paving workers and influence of work conditions and practices. Ann Occup Hyg. 2012;56(2):138-47. doi: 10.1093/annhyg/mer088.

69. Kriech AJ, Osborn LV, Wissel HL, Redman AP, Smith LA, Dobbs TE. Generation of Bitumen Fumes Using Two Fume Generation Protocols and Comparison to Worker Industrial Hygiene Exposures. JOccupEnvironHyg. 2007;4(1 supp):S6-19.

70. International Program on Chemical Safety, United Nations Environment Programme, Inter- Organization Programme for the Sound Management of Chemicals, World Health Organization, Wess J. Asphalt (bitumen): CICAD 59. Geneva: World Health Organization; 2004.

71. Burstyn I, Kromhout H, Boffetta P. Literature review of levels and determinants of exposure to potential carcinogens and other agents in the road construction industry. Am Ind Hyg Assoc J. 2000;61(5):715-26.

72. Burstyn I, Ferrari P, Wegh H, Heederik D, Kromhout H. Characterizing Worker Exposure to Bitumen During Hot Mix Paving and Asphalt Mixing Operations. Am Ind Hyg Assoc J. 2002;63(3):293-9.

73. NIOSH. Polycyclic Aromatic Compounds, Total (PACs) 5800 - NIOSH Manual of Analytical Methods (NMAM) - NMAM Online - Methods Numerical Listing 4001-6000. 1998.

74. NIOSH, Burr GA, Tepper A, Feng A, Olsen L, Miller A. NIOSH Health Hazard Evaluation Report: HETA 2001-0536-2864 Crumb-Rubber Modified Asphalt Paving: Occupational Exposures and Acute Health Effects. 2002.

75. Osborn LV, Kurek JT, Kriech AJ, Fehsenfeld FM. Luminescence spectroscopy as a screening tool for the potential carcinogenicity of asphalt fumes. Journal of Environmental Monitoring. 2001;3(2):185-90.

76. Osborn LV, Snawder JE, Kriech AJ, Cavallari JM, McClean MD, Herrick RF, et al. Personal Breathing Zone Exposures among Hot-Mix Asphalt Paving Workers; Preliminary Analysis for Trends and Analysis of Work Practices That Resulted in the Highest Exposure Concentrations. Journal of Occupational and Environmental Hygiene. 2013;10(12):663-73. doi: 10.1080/15459624.2013.831981.

77. Kriech AJ, Osborn LV, Trumbore DC, Kurek JT, Wissel HL, Rosinski KD. Evaluation of worker exposure to asphalt roofing fumes: influence of work practices and materials. Journal of Occupational and Environmental Hygiene. 2004;1(2):88-98.

78. Trumbore DC. Airborne Exposure to Polycyclic Aromatic Compounds among Workers in Asphalt and Asphalt Roofing Manufacturing Facilities. Unpublished Manuscript. 2014.

79. National Toxicology Program. Toxicology and Carcinogenesis Studies of Naphthalene (CAS No. 91-20-3) in F344/N Rats (Inhalation Studies)(NTP Technical Report No. 500; NIH Publ. No. 01- 4434). 2000.

80. Cavallari JM, Zwack LM, Lange CR, Herrick RF, McClean MD. Temperature-dependent emission concentrations of polycyclic aromatic hydrocarbons in paving and built-up roofing asphalts. Ann Occup Hyg. 2012;56(2):148-60. doi: 10.1093/annhyg/mer107.

81. Lindsay F, Semple S, Robertson A, Cherrie J. Development of a biologically relevant dermal sampler. Annals of Occupational Hygiene. 2006;50(1):85-94.

82. Vaananen V, Hameila M, Kalliokoski P, Nykyri E, Heikkila P. Dermal Exposure to Polycyclic Aromatic Hydrocarbons Among Road Pavers. Annals of Occupational Hygiene. 2005;49(2):167-78.

83. McClean MD, Rinehart RD, Ngo L, Eisen EA, Kelsey KT, Herrick RF. Inhalation and dermal exposure among asphalt paving workers. Ann Occup Hyg. 2004;48(8):663-71.

84. Olsen LD, Snawder JE, Kriech AJ, Osborn LV. Development of a 5-Layer Passive Organic Dermal (POD) Sampler. Polycyclic Aromatic Compounds. 2011;31(3):154-72. doi: 10.1080/10406638.2011.581262.

85. Olsson A, Kromhout H, Agostini M, Hansen J, Lassen CF, Johansen C, et al. A Case- Control Study of Lung Cancer Nested in a Cohort of European Asphalt Workers. Environ Health Perspect. 2010;118(10):1418-24.

86. de Joode BV, Brouwer DH, Vermeulen R, Van Hemmen JJ, Heederik D, Kromhout H. Dream: a Method for Semi-Quantitative Dermal Exposure Assessment. Annals of Occupational Hygiene. 2003;47(1):71-87.

87. Hicks JB. Asphalt Industry Cross-Sectional Exposure Assessment Study. Appl Occup Environ Hyg. 1995;10(10):840-8.

88. Fustinoni S, Campo L, Cirla PE, Martinotti I, Buratti M, Longhi O, et al. Dermal exposure to polycyclic aromatic hydrocarbons in asphalt workers. Occupational and Environmental Medicine. 2010;67(7):456-63.

889. Cavallari JM, Osborn LV, Snawder JE, Kriech AJ, Olsen LD, Herrick RF, et al. Predictors of dermal exposures to polycyclic aromatic compounds among hot-mix asphalt paving workers. Ann Occup Hyg. 2012;56(2):125-37. doi: 10.1093/annhyg/mer108.

90. Knecht U, Walter D, Woitowitz HJ. Human-experimentelle Untersuchungen zur dermalen Resorption von Bitumen-Emissionen (Standardized human investigations on the precutaneous absorption of bitumen emissions). Gefahrstoffe-Reinhaltung der Luft. 2001;61:503-6.

91. van Rooij JGM. Review of Skin Permeation Hazard of Bitumen Fumes. JOccupEnvironHyg. 2007;4:237-44.

92. Pesch B, Spickenheuer A, Kendzia B, Schindler B, Welge P, Marczynski B, et al. Urinary metabolites of polycyclic aromatic hydrocarbons in workers exposed to vapours and aerosols of bitumen. Archives of Toxicology. 2011:1-11.

93. McClean MD, Osborn LV, Snawder JE, Olsen LD, Kriech AJ, Sjodin A, et al. Using Urinary Biomarkers of Polycyclic Aromatic Compound Exposure to Guide Exposure-Reduction Strategies Among Asphalt Paving Workers. Ann Occup Hyg. 2012;56(9):1013-24. Epub 2012/09/25. doi: 10.1093/annhyg/mes058.

94. NIOSH, Butler M, Burr G, Dankovic D, Lunsford R, Miller A, et al. Hazard Review: Health Effects of Occupational Exposure to Asphalt. 2001 2001-110.

95. Kriech AJ, Osborn LV, Prowell BD, Redman AP, West RC, editors. Comparison of worker breathing zone exposures between hot mix asphalt and warm mix asphalt applications. National Asphalt Pavement Association; 2011.

96. Rhomberg L, Goodman JE, Butler E, Mayfield D, Nascarella M, Williams D. Assessment of the Potential Cancer Risk Associated with Occupational Exposures to BURA. Unpublished Manuscript. 2014.

97. Axten CW, Fayerweather WE, Trumbore DC, Mueller DJ, Sampson AF. Asphalt Fume Exposure Levels in North American Asphalt Production and Roofing Manufacturing Operations. JOccupEnvironHyg. 2012;9(3):172-84. doi: 10.1080/15459624.2012.659980.

98. Calzavara TS, Carter CM, Axten C. Air sampling methodology for asphalt fume in asphalt production and asphalt roofing manufacturing facilities: total particulate sampler versus inhalable particulate sampler. Appl Occup Environ Hyg. 2003;18(5):358-67.

99. Gamble JF, Nicolich MJ, Barone NJ, Vincent WJ. Exposure-response of asphalt fumes with changes in pulmonary function and symptoms. Scand J Work Environ Health. 1999;25(3):186-206.

100. Burstyn I, Kromhout H, Kauppinen T, Heikkila P, Boffetta P. Statistical modelling of the determinants of historical exposure to bitumen and polycyclic aromatic hydrocarbons among paving workers. Ann Occup Hyg. 2000;44(1):43-56.

101. Deygout F, Le Coutaller P. Field sampling investigations within the road paving industry. JOccupEnvironHyg. 2010;7(2):103-8.

102. Mickelsen RL, Shulman SA, Kriech AJ, Osborn LV, Redman AP. Status of Worker Exposure to Asphalt Paving Fumes with the Use of Engineering Controls. Environmental Science & Technology. 2006;40(18):5661-7.

103. Heikkila P, Riala R, Hameila M, Nykyri E, Pfaffli P. Occupational Exposure to Bitumen During Road Paving. Am Ind Hyg Assoc J. 2002;63(2):156-65.

104. Bosse GM, Wadia SA, Padmanabhan P. Hot asphalt burns: a review of injuries and management options. The American Journal of Emergency Medicine. 2014;32(7):820.e1-.e3. doi: 10.1016/j.ajem.2014.01.007.

105. American Conference of Industrial Hygienists (ACGIH). Asphalt Fumes: TLV® Chemical Substances 7th Edition Documentation. 1330 Kemper Meadow Drive, Cincinnati, OH 45240-1634: ACGIH, 2001.

106. Goyak KO, McKee RH, Minsavage GD, McGowan C, Daughtrey WC, Freeman JJ. Paving Asphalt Products Exhibit a Lack of Carcinogenic and Mutagenic Activity. International Journal of Toxicology. 2011;30(5):492-7. doi: 10.1177/1091581811415700.

107. IARC. Bitumens and Bitumen Emissions, and Some N- and S-Heterocyclic Polycyclic Aromatic Hydrocarbons. Lyon, FR: International Agency for Research on Cancer; 2013. 342 p.

108. Clark CR, Burnett DM, Parker CM, Arp EW, Swanson MS, Minsavage GD, et al. Asphalt fume dermal carcinogenicity potential: I. dermal carcinogenicity evaluation of asphalt (bitumen) fume condensates. Regul Toxicol Pharmacol. 2011;61(1):9-16. doi: 10.1016/j.yrtph.2011.04.003.

109. Freeman JJ, Schreiner CA, Beazley S, Burnett DM, Clark CR, Mahagaokar S, et al. Asphalt fume dermal carcinogenicity potential: II. Initiation-promotion assay of Type III built-up roofing asphalt. Regulatory Toxicology and Pharmacology. 2011;10(1):17-22. doi: 10.1016/j.yrtph.2011.05.008.

110. Carrillo JC, Di Caprio E, Gaul S, Hedelin A, Kotsiki C, Leon Paumen M, et al. Hazard classification and labelling of petroleum substances in the European Economic Area-2014. CONCAWE, Brussels (Belgium), 2014 Report 10/14.

111. Carrillo JC, del Castillo F, Gaul S, Hedelin A, Korikis S, Kotsiki C, et al. Hazard classification and labelling of petroleum substances in the European Economic Area-2012. CONCAWE, Brussels (Belgium), 2012 Report No. 8/12.

112. NIOSH. Phase III survey report No. 3: Worker Exposure to Polyaromatic Hydrocarbons at Selected Petroleum Refinery Process Units. Coastal States Petrochemical Company Refinery, Corpus Christi, TX. Cincinnati, OH: United States Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, 1980 NIOSH Contract No. 210-78-0082.

113. NIOSH. Technical Report: Petroleum Refinery Workers Exposure to PAHs at Fluid Catalytic Cracker, Coker, and Asphalt Processing Units. Cincinnati, OH: United States Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, 1983 DHHS (NIOSH) 83-111.

114. Claydon MFC. Review of bitumen fume exposures and guidance on measurement. The Hague: CONCAWE, 1984 6/84.

115. Boogaard PJ, van Sittert NJ. Urinary 1-hydroxypyrene as biomarker of exposure to polycyclic aromatic hydrocarbons in workers in petrochemical industries: baseline values and dermal uptake. Sci Total Environ. 1995;163(1-3):203-9.

116. Futagaki SK. Petroleum Refinery Workers Exposure to PAHs at Fluid Catalytic Cracker, Coker, and Asphalt Processing Units. United States Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Institute for Occupational Safety and Health, 1981 NIOSH Contract No. 210-78-0082.

117. Deygout F, Carre D, Auburtin G, Lombardi B. Personal exposure to PAHs in the refinery during truck loading of bitumen. Journal of Occupational and Environmental Hygiene. 2011;8(10):D97-D100. doi: 10.1080/15459624.2011.613293.

THE **BITUMEN** INDUSTRY – A Global Perspective

asphalt institute | eurobitume

ISBN: 978-1-934154-73-1
IS-230