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Number 24

EMISSION SCENARIO DOCUMENT ON TRANSPORT AND STORAGE OF CHEMICALS

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Series on Emission Scenario Documents No. 24

EMISSION SCENARIO DOCUMENT ON TRANSPORT AND STORAGE OF CHEMICALS

IOMC

INTER-ORGANISATION PROGRAMME FOR THE SOUND MANAGEMENT OF CHEMICALS

A cooperative agreement among

UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD

Environment Directorate

Organisation for Economic Co-operation and Development

Paris 2009

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EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources and release pathways of chemicals during their transport and storage in a wide range of industries, to help estimate releases of chemicals into the environment. This ESD covers the transport and storage of chemicals either as pure chemicals or as components of finished products. However, it does not consider the following: mixed waste streams, radioactive substances, biological and infectious materials and foodstuffs.

This ESD may be periodically updated to reflect changes in the industry and new information available, and extended to cover the industry area in countries other than the lead (the UK). Users of the document are encouraged to submit comments, corrections, updates, and new information to the OECD Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the OECD Task Force on Environmental Exposure Assessment, which will review the comments every two years so that the lead country can update the document. Submitted information will also be made available to users within the OECD web site (www.oecd.org/env/riskassessment).

How to use this document

The information in this document should be considered in the context of the situation for which estimates of chemical releases are being made. The document can be used as a framework to identify the information needed, or its recommended approaches can be used together with suggested default values to provide estimates. Where specific information is available, this should be used in preference to the default values. At all times, starting information and results should be critically reviewed to ensure they are valid and appropriate.

Whilst this report may help to provide an estimate of potential chemical releases into the environment, it should not be used as an alternative to more detailed procedures (where these are available) used by industry to estimate emissions from specific processes. It is not practical for the ESD to give detailed emission factors for all processes and chemicals. Furthermore, within the chemicals and petroleum sector, products and the technology to store and transport them are continually evolving, and these may have significant impacts on the resulting emissions which are not reflected in the ESD.

The report also provides information on the regulations governing transport and storage of chemicals. However, the intention here is not to give a comprehensive account of all relevant legislation, but rather to summarise the main points that may influence the types of transport and storage system used, so that appropriate emissions scenarios can be selected. Regulations are necessarily complex and not all aspects are covered in this ESD. The full regulations should therefore be consulted on the types of transport and storage system that can be used for a specific chemical.

Coverage

Unlike other documents in this series, the information in this document does not relate to any specific industry category or to specific use categories. In principle the approaches here could be applicable to any area of chemical uses, and so to any industry and use category.

How this document was developed

This ESD was produced in consultation with trade associations and industry based mainly in the UK. The ESD has been overseen by the OECD Task Force on Environmental Exposure Assessment.

Information was collected during 2005 and was largely provided by industry practitioners with a breadth of knowledge and experience. Published sources are cited where appropriate, but most of the information did not come from such sources and was based on the knowledge and experience of the experts consulted. Unless a specific source is cited, it should be assumed that the information was derived from consulted experts. Where a value has been derived statistically, for example an average or a 90th percentile, this is indicated in the ESD. In cases where values are based on expert judgment, these are intended to represent a realistic worst case – not the absolute worst possible case, but the worst which might reasonably be expected to occur under normal conditions.

A first draft ESD was discussed by the OECD Task Force at its 14th meeting in September 2006. The updated draft was circulated again to the Task Force members for their comments in May 2007, and was approved at the 15th meeting of the Task Force in December 2007.

The original document (with identical technical content) was published by the Environment Agency of England and Wales in 2007 (Environment Agency, 2007).

TABLE OF CONTENTS

1. OVERVIEW OF THE TRANSPORT AND STORAGE OF CHEMICALS

1.1 Introduction

Chemicals are transported and stored by a number of different industry sectors which include producers, downstream users, distributors and consumers of chemicals and products containing chemicals, as well as tanker cleaning, drum cleaning and recycling operations. As a result this emission scenario document (ESD) needs to be considered in a different light to other ESDs, which typically concentrate on a single industry area. Further, each industry area can use a range of transport and storage systems, where the system used depends more on the properties of the chemical and economics than the industry area. Thus, transport and storage is a cross-cutting area relevant to all industry categories.

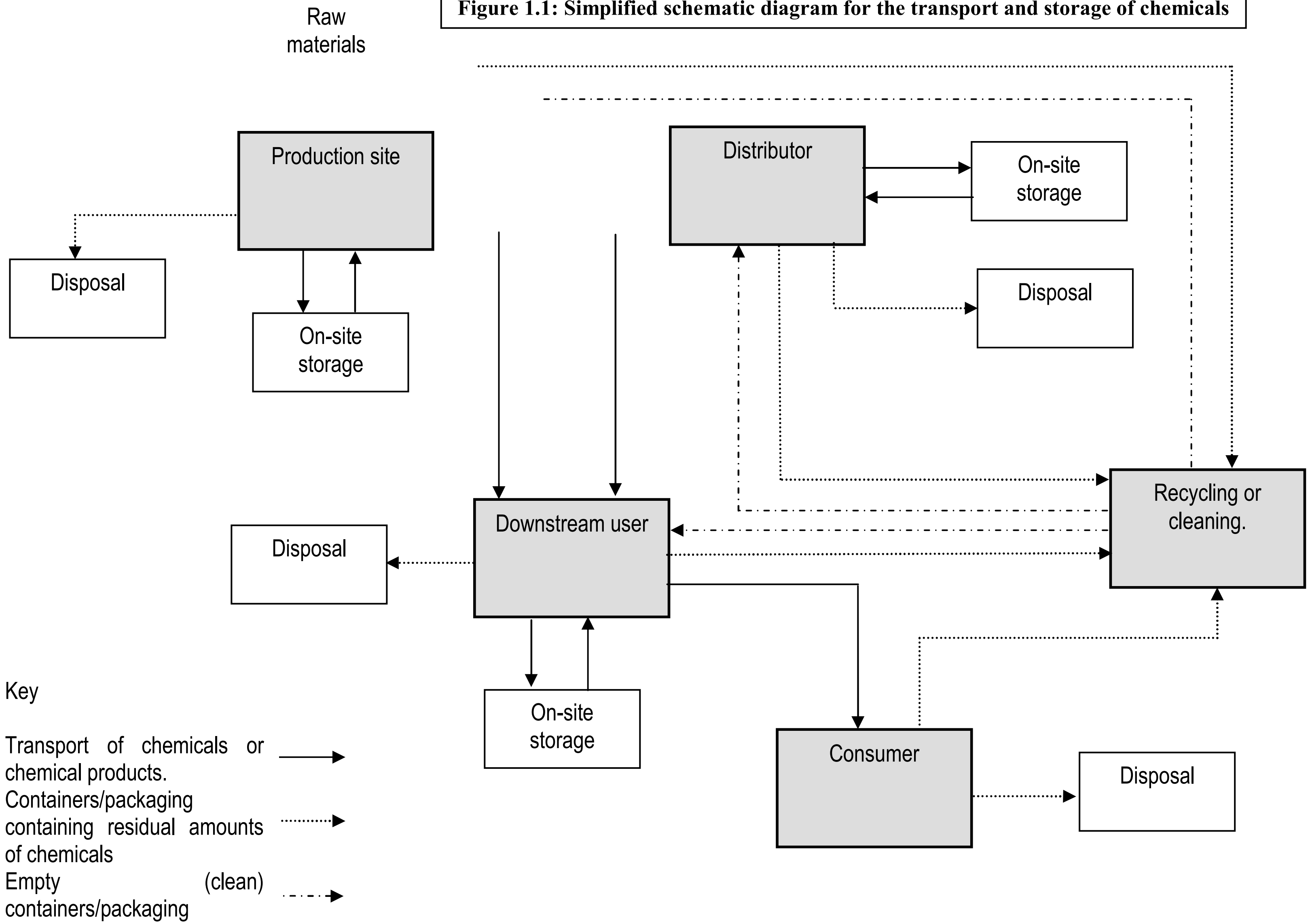
This report has been developed using published information and information provided by chemical companies and trade associations within the United Kingdom. In particular the following organisations have provided useful data and comments and their contribution is gratefully acknowledged: the British Chemical Distributors and Traders Association, Industrial Packaging Association, Ineos Chlor Ltd., National Road Tanker Cleaners Association, Solvents Industry Association and UK Petroleum Industry Association.

For the purpose of this document, the transport and storage of chemicals has been divided into the following main processes that can potentially lead to emissions to the environment:

- filling of transport and/or storage system;
- emptying of transport and/or storage system;
- storage of liquids in tanks;
- storage of solids in open storage;
- transport in pipelines;
- washing and cleaning (recycling) of transport and/or storage system;
- disposal of packaging.

These processes can occur at one or more sites within the lifecycle of a given chemical. An example is shown in Figure 1.1, but many more combinations can exist.

Figure 1.1: Simplified schematic diagram for the transport and storage of chemicals



Each of these processes relates to the different types of transport and storage systems. Emission scenarios must therefore be derived for different combinations of transport and storage systems as required. The specific transport and storage systems considered in this ESD are summarised below:

- road tankers;
- rail tankers;
- ship tankers;
- pipelines;
- intermediate bulk containers (IBCs);
- drums;
- bags;
- storage tanks;
- silos.

A key aspect when using this ESD is to identify the appropriate type of transport and storage system for a specific chemical. Generic guidance is given in Section 0, but many possible types of transport and storage can be used for a given chemical. It is therefore recommended that the guidance given here is used only for an initial estimate of the emissions from transport and storage. If more refined estimates are required, then it may be necessary to obtain further, more detailed, information on the exact transport and storage systems to be used for the chemical under consideration.

2. SYSTEMS USED IN THE TRANSPORT AND STORAGE OF CHEMICALS

The choice of container system for the transport of chemicals is usually primarily influenced by safety and chemical compatibility considerations, but is also dictated to some extent by the manufacturer and marketing and economic considerations (Olsson and Chapman, 1996). Factors affecting the choice of transport and storage system are considered in detail in Section 0 and the typical sizes of transport and storage systems for use in the emission scenarios are summarised in Table 0.1.

2.1 Bulk containers

2.1.1 Road tankers

Road tankers are the preferred method of delivery of most petroleum products to industrial users and filling stations[1] and are also used to transport a wide range of other chemical types. Pipelines (see Section 0) are the more usual method of transport of petroleum products from refineries to storage terminals within the UK. Road tankers for the transport of petroleum products are usually around 44 tonnes capacity gross weight (net weight around 25 tonnes)[2] but smaller tankers (gross weight around 18 tonnes) are used in rural areas. The tankers are loaded at the storage terminal and modern automated terminals are equipped with loading gantries where the tanker can be loaded from the bottom, while the vapours expelled during filling are collected and passed through a vapour recovery system which converts them back to liquid form. A similar system also operates at filling stations, where the vapours expelled from the underground tanks are recovered by the tanker and processed back at the terminal. Specialised tankers are used to transport petroleum products such as bitumen, fuel oil and LPG.

Similar tankers are also used to transport a range of other chemicals, including liquids and solids, within the UK.

2.1.2 Rail tankers

Rail tankers are used for the bulk transport of chemicals within the United Kingdom, with an estimated 11 million tonnes of petroleum products and chemicals transported by this method in the UK in 2003. Rail tankers are generally dedicated to a specific product and are not routinely cleaned.

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[1] See http://www.ukpia.com/industry_information/distribution.aspx.

[2] Gross weight refers to the weight of the tanker plus contents. Net weight refers to the weight of chemical carried by such tankers.

Rail tankers are also an important method of transport in other parts of Europe and the world. For example, there are an estimated 170,000 rail tankers in the United States (Olsson and Chapman, 1996). Around 15 per cent of these are used to transport pressurised products such as anhydrous ammonia and propane.

The interior surfaces of tankers used to transport liquid products are usually either unlined or lined steel and as such, are compatible with a wide range of products. Lining materials can include synthetic rubber, phenolic or modified epoxy resins or corrosion-resistant materials such as aluminium, nickel-bearing steel or stainless steel (Olsson and Chapman, 1996). Tanker cars can also be fitted with internal or external heating coils, or in some cases may be insulated, to allow the transport of products that solidify at ambient temperatures. The capacity of tanker cars can be as large as 130,000 litres.

Bulk rail cars, especially covered hopper cars, can be used for the transport of bulk substances. However, such specialised cars require a large investment and so only tend to be used where such investment can be justified (Olsson and Chapman, 1996). They are often used in closed-loop operations where the trains shuttle between the filling and discharge points.

2.1.3 Shipping

Large volumes of petroleum products can be transported by coastal tankers as an alternative to transport via pipelines (see Section 0). Around fifteen sea tanker terminals exist in the United Kingdom. The UK is a net exporter of oil products (UKPIA, 2004).

As well as petroleum products, shipping may be used to transport bulk raw materials such as minerals and ores. In addition, other forms of transport (such as road tankers) and containers may be carried by ship. Within other parts of Europe, barges may be used to transport chemicals.

2.1.4 Pipelines

Pipelines are often used to transport chemicals. This is particularly so for integrated chemical manufacturing plants, where the chemical intermediate required for a process is piped directly from the manufacturing unit of the intermediate. Such pipelines are usually only feasible where relatively short distances are involved (that is, both of the plants involved are close by).

An exception to this is petroleum products (and natural gas) distribution. The UK is criss-crossed with a network of pipelines for the transport of petroleum products from refineries to large scale storage terminals[3]. The pipelines are usually used for the transport of petrol, diesel and jet fuel and around 30 million tonnes of products are transported this way each year in the UK. This figure is equivalent to around 800,000 road tanker journeys. The pipelines are controlled with computer systems linked to sensors and automated valves, allowing the speed of flow to be optimized and limiting the amount of mixing of different products within the pipeline.

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[3] See http://www.ukpia.com/industry_information/distribution.aspx.

Some major UK airports are fed directly by pipelines into the airport fuel store, although the majority are fed by road tankers. Fuel distribution across the airport can also be by pipeline, although relatively few airports have such internal pipeline and hydrant systems. Many airports use dedicated aircraft refuelling tankers which transfer the product directly from the storage tanks to the aircraft.

2.2 Semi-bulk containers

Semi-bulk containers are intermediary between bulk containers (Section 0) and individual containers (Section 0) (Olsson and Chapman, 1996). Semi-bulk containers are also known as intermediate bulk containers (IBCs). These generally have a volume capacity ranging from 400 litres to 2,000 litres and a net weight of 225 kg to 2,270 kg. The containers are usually handled by cranes and/or fork lift trucks and can be either returnable or non-returnable. Returnable IBCs are usually made of metal, and may be collapsible in order to minimise the cost of return. Non-returnable IBCs are normally made of multiwall corrugated paper board, typically with heavy gauge plastic liners, with pallets to facilitate moving and handling. The choice between returnable and non-returnable is usually based on economic considerations and also the normal practice within a given industry. Returnable IBCs may be reconditioned (cleaned) prior to re-use.

The most common type of IBC in the United States is the composite IBC, comprising a 275-330 gallon (1,040-1,250 litre) rigid plastic container encased in a steel tube or wire cage[4]. The container and cage are fixed to a wood, metal or plastic pallet. This type of IBC can also be reconditioned (cleaned) and re-used.

A further type of IBC is the flexible IBC usually made from textile, film or other flexible material. These are also sometimes known as big bags (see Section 0).

The European Commission (2004) indicates that in Europe, the upper capacity limits for IBCs are 3,000 litres for hard IBCs and 1,500 litres for flexible IBCs. The most common types of IBCs used are metallic IBCs, hard plastic IBCs and flexible IBCs.

According to the Industrial Packaging Association's (IPA) website[5] IBCs have been in use in the United Kingdom for over 50 years, but it is only since the early 1980s that a wide range of modular, composite and flexible designs have been introduced into the UK, and since that time the market has grown significantly. IBCs are seen as a highly versatile transport and storage medium for quantities of raw materials above the standard 200 litre drum[7], while remaining more manageable than road tankers. IBCs now represent a significant proportion of the transport and storage systems used, both in the United Kingdom and internationally, for both dangerous and non-dangerous goods. They can be used for chemical forms ranging from powders to light liquids to highly viscous products.

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[4] See http://www.reusablepackaging.org/emptyibc.cfm

[5] See http://www.theipa.co.uk/ibcs.htm

2.3 Smaller bulk containers

2.3.1 Steel drums and pails

Drums are single-walled, cylindrical or bilged[6] containers of volume 49 to 416 litres (Olsson and Chapman, 1996). Pails are containers with a capacity of 45 litres (12 US gallons) or less, usually of cylindrical or truncated cone shape and often with a carrying handle. Around 80 per cent of all drums in the United States have a capacity of 208 litres[7] (55 US gallons). The other main standard sizes available include 19 litres (5 US gallons), 38 litres (10 US gallons), 61 litres (16 US gallons) and 114 litres (30 US gallons).

The IPA's website[8] provides some information on the use of steel drums in the UK. Steel drums have been used for the transport and storage of chemicals from the beginning of the twentieth century. The diameter of steel drums ranges from 165 mm to 571.5 mm. Although a range of sizes of steel drums are produced, around 86 per cent by weight of the total quantity manufactured in the UK are of 210 litre volume[7].

The most important considerations when choosing a drum (or pail) for a given application are the wall thickness and interior lining. The wall thickness gives an indication of the physical strength of the drum. The choice is dependent on the chemical properties of the substance being carried. The thickness of steel drums is generally in the range 0.328-2.4 mm. The different categories of drums are summarised in Table 0.1.

Table 0.1 Categories of drum (Olsson and Chapman, 1996)

Category of drum	Thickness of drum wall
Heavy drums	1.09-2.4 mm
Light drums	0.328-0.960 mm

Drums with non-removable ends (known as tight-end or tight-head drums) are usually equipped with two screw-type openings, one of 19 mm diameter and one of 51 mm diameter, although other sizes of opening are also available (Olsson and Chapman, 1996). The plug or gasket that covers the opening can be plastic or metal.

Common lining materials include phenolic resins, polyethylene or a combination of phenolic and epoxy resins (Olsson and Chapman, 1996). Most lining materials are applied by spray-coating.

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[6] Barrel-shaped containers.

[7] In the literature this size of drum is referred to as 200, 205, 208 and 210 litres in various different publications. Throughout this report the volume quoted in the various publications is given but it is taken that these sizes refer to essentially the same size drum and 205 litres is considered to be typical.

[8] http://www.theipa.co.uk/steel-drums.htm

Polyethylene-coated drums are used for particularly aggressive products and have been used for the storage and transport of organic and inorganic acids, food products, paints, janitorial supplies, surfactants and agrochemicals.

Drums can be reconditioned and re-used under certain circumstances (Olsson and Chapman, 1996). This drum reconditioning is carried out by specialist commercial operators.

Some metal drums are made from aluminium, monel, stainless steel or nickel (Olsson and Chapman, 1996). These are for use in very severe environments and the drums tend to have a very long service life.

Steel drums are used to transport virtually any substance that is capable of being poured, from foodstuffs to hazardous chemicals, including powders, pastes, greases and viscous liquids. Steel drums remain the most popular form of container used for shipping goods. According to Brody and Marsh (1997), over 75 per cent of new drums are used for liquids, with the remainder used for viscous and dry products. Chemicals account for around 35 per cent of the products carried in drums, followed by petroleum products and lubricants (15 per cent of the market), paints, coatings and solvents (ten per cent of the market), food and pharmaceutical products (five per cent of the market) and janitorial supplies, cleaning compounds and soaps (five per cent of the market). The remaining 30 per cent of the market was not given (presumably this consists of many smaller groups of products).

2.3.2 Plastic drums

Plastic drums have widespread use within the chemical industry and are used for the transport and storage of many liquids, semi-solids, powders and granulated products (Olsson and Chapman, 1996). Two main types of plastic drum are used: free standing plastic drums and plastic inserts for steel or fibre outer drums (composite drums). The principal advantage of plastic drums is their resistance to corrosion, provided they are compatible with the material being carried.

The capacities of plastic drums in the United States range from 9.5 litres to 208 litres[7] (2.5 to 55 US gallons) and they are generally made from polyolefins (Olsson and Chapman, 1996). Small drums are frequently transported within corrugated boxes for ease of handling. The large drums, especially those of 208 litre capacity[7], are usually handled by hand trucks, fork lift trucks or cranes.

Plastic drums can be manufactured with either an integral or removable head, depending on the need of the customer (Olsson and Chapman, 1996). Integral or tight-head drums are the more common type used in the chemical industry, whereas open-head drums (to which a separate cover can be fastened) are generally used by the food industry. The choice between the two styles is often determined by the requirements for cleaning of the drum interior.

Composite drums consist of a semi-rigid plastic liner (usually polyethylene) and either a steel or fibre outer container (Olsson and Chapman, 1996). These drums are strong-enough to be handled like a steel drum, but allow transport and storage of chemicals that cannot be safely transported in steel or fibre drums. Composite drums have a typical capacity of 19-208 litres[7] (5-55 US gallons) and are used in the chemical, pharmaceutical and food industries.

According to the IPA[9], a range of plastic drums are now available for use in various chemical industries, thanks to developments over the last 20 years in polymer extrusion blow moulding and rotomoulding technologies. Plastic drums in the UK can be produced with a variety of closure systems to meet the specific requirements of the customer, including automatic filling lines. The properties of plastics allow for more flexibility in the design of the drum, which in turn results in better drainage of the contents and lower levels of product residues in the drum.

2.3.3 Fibre drums

Fibre drums are cylindrical containers made from wound layers of glued fibreboard (Olsson and Chapman, 1996). The ends can be made from metal, plastic or fibreboard.

The capacities of fibre drums in the United States typically range from 4 litres to 380 litres (around 1 US gallon to 100 US gallons) but large volumes are also available (up to around 450 litres) (Olsson and Chapman, 1996). The net weight limit of fibre drums is generally around 250 kg but can be up to around 400 kg for the largest drums.

Fibre drums are available in a wide range of sizes and can be sized to meet specific product volumes, unlike metal drums which are available in a relatively limited number of standard sizes (See Section 0).

Fibre drums are mainly used for the transport of dry, granular solids and semi-solids, but can also be used in combination with a liner and/or coating for the transport of liquid products (Olsson and Chapman, 1996 – see also Section 0).

The most common design of fibre drum consists of a fibre shell fitted with a metal chime at the bottom (the chime connects the bottom securely to the side wall to prevent leakage) (Olsson and Chapman, 1996). The top of the container is grooved so that a cover and locking band can be applied. Several types of closures can be used including friction or telescoping, slip-on covers secured by gummed or pressure-sensitive tape, lever-locking rings or other types of bands, expanding or crimped lids, and metal lugs or clips.

According to the European Commission (2004) composite containers are also available, made from an internal glass, porcelain or earthenware container and an external (cardboard or wood) package. This type of container can be reconditioned.

The IPA's website[10] indicates that in the UK (and globally), fibre drums are used for the transport and storage of powdered, granular, paste, solid and semi-liquid products. Typical types of products packed in such systems include the following:

- powders and granules;
- adhesives;

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[9] http://www.theipa.co.uk/plastic-drums.htm

[10] http://www.theipa.co.uk/fibre-drums.htm

- foodstuffs and flavourings;
- dyestuffs and colourants;
- wire and cable/metal – wound around a fibre inner core;
- rolled sheet material.

Linings that are used in such drums include the following:

- polyethylene lining, which allows semi-liquids to be packed;
- polyfoil lining, which offers enhanced moisture protection;
- silicone lining, which has high release properties and is especially suitable for adhesives.

According to the IPA, fibre drums in the United Kingdom are produced in specific diameters with fully customisable heights, and range in capacities from five litres to 270 litres. All drums have a fully removable lid, produced from fibre, plastic or steel, allowing access to the drum. The global standard for securing the lid in place is by a metal closure band, with a lever or latch action, which can be secured with a tamper evident seal.

2.3.4 Bags

Bags or sacks are generally used for dry chemicals (Olsson and Chapman, 1996). The choice of bag type is usually based on the protection needs of the substance and the requirements of the distribution network. Bags can be custom-made for specific products. The terms bag and sack tend to be used interchangeably, although the term sack is generally applied to heavier-duty bags.

Several types of bags and sacks are commonly used in industry. As well as different materials, they also vary in terms of how they are closed or in style (gusseted or flat).

The most common size of bag or sack is normally around 25 kg for ease of single person handling. However, larger bags, known as big bags or supersacks, with a capacity of 1,000 kg are becoming increasingly common for the transport of chemicals. These can be considered a form of IBC (see Section 0).

2.3.4.1 Textile bags

Textile bags are made from natural fibres such as cotton and Hessian (burlap) (Olsson and Chapman, 1996). Textile bags are gradually being replaced by various combinations of textile components with plastic or paper, multiwall paper or plastic bags.

Hessian bags can be made in various weights and are very strong, with a high tear and snag resistance (Olsson and Chapman, 1996). They are also available with special finishes and may be printed for brand identification. They are used largely for the transport and storage of agricultural crops and animal feeds.

Cotton fabrics are used to transport goods such as flour, processed grain, animal feeds and seeds (Olsson and Chapman, 1996). They have a good resale value but the high price of the bags means that use has declined significantly in recent years.

2.3.4.2 Laminated textile bags

These bags are usually made from Hessian or cotton bonded to one or more layers (plies) of a combination of creped kraft paper, plastic film and/or aluminium foil (Olsson and Chapman, 1996). The materials used are selected to give the appropriate degree and type of protection to the products being transported. The textile can form the outer layer or can be an intermediate layer within the bag structure. This type of bag is very strong, with good tear and puncture resistance. The bags can be stacked higher than conventional multiwall bags (see Section 0) and can be manufactured to be weather resistant as well as moisture, odour, acid and grease resistant.

The types of products transported in laminated textile bags include petrochemicals, drugs, insecticides, fertilizers and seeds (Olsson and Chapman, 1996). They are generally used to transport products with a high intrinsic value and can be used as an alternative to rigid drums where minimising storage and shipping space is important.

2.3.4.3 Multiwall paper bags

This type of bag is by far the most common type of bag used for transport and storage of chemicals (Olsson and Chapman, 1996). Multiwall bags generally consist of two to six layers (plies) of heavy-duty kraft paper. The inner plies may be plastic coated or consist of plastic films. The individual plies may also be treated to improve wet-strength, acid or alkali resistance or to provide moisture barriers or non-skid surfaces.

Multiwall paper bags are used particularly for the transport of agricultural products, but also chemicals, food and rock products.

2.3.4.4 Plastic bags

Plastic bags usually consist of a single, heavy-duty wall of plastic film, woven sheets of plastic tape, or laminates (Olsson and Chapman, 1996). The plastics used are mainly polyethylene or polypropylene.

Plastic bags can be filled and closed using conventional equipment. Heat sealing of open mouth bags can be used to provide a moisture-resistant closure.

Woven plastic bags only have limited use within the chemical industry, although they may be used for some agricultural (and other industrial) applications where they compete with Hessian bags.

2.3.5 Carboys and bottles

Carboys are straight-sided, cylindrical bottles with a capacity of 10 to 50 litres (Olsson and Chapman, 1996). They are generally made of glass but can also be made of plastic, earthenware or porcelain. They are usually enclosed in a protective outer container or frame (in order to protect the glass from damage and to sometimes assist in stacking and handling during transport). Carboys are traditionally used for transport of liquids that can only safely be held in glass containers, or products of extremely high purity. Carboys are available in one-way and returnable forms.

In the EU, glass bottles for the transport and storage of chemicals do not normally exceed five litres capacity, with most being ≤ 2.5 litres capacity (European Commission, 2004). The most common use for chemicals supplied this way is laboratory use.

2.4 Compressed gas cylinders

Compressed gases are, by their nature, transported in pressurised cylinders and so have limited potential for release during transport and storage. Some compressed gases are also transported in bulk in pressurised road and rail tankers. For these systems, high standards of safety are applied, for example a pre-delivery inspection is always undertaken and gas cylinders and other transportable pressure receptacles are subject to an approval regime and require periodic testing. In addition, pressurised gas cylinders and pressurised road and rail tankers are all dedicated to specific chemicals or products and are not cleaned between deliveries. Any substance remaining in the tanker is taken back to the production site for reprocessing or remains in the tanker as part of the next delivery. Therefore the potential release to the environment would be low and so the transport and storage of compressed gases are not considered further in this ESD.

2.5 Containers for final (consumer) products

Consumer products containing chemicals (usually as formulated products such as paints, cleaning agents, bleach, personal care products, sealants, adhesives) are supplied in a wide range of containers including tins, tubes, boxes, bottles and spray cans manufactured out of metal, plastic, glass, cardboard and so on.

Storage of fuel at home or the workplace (unless specifically licensed) is restricted by law in the United Kingdom to either two metal containers with a maximum capacity of 10 litres each or two approved plastic containers with a maximum capacity of five litres each[11]. These containers should be designed for purpose, fitted with a screw-cap or closure to prevent leakage of liquid or vapour, and should be clearly labelled.

Losses during the use of consumer products are related to the lifecycle of the particular product and so should not be considered in the ESD for transport and storage. However, some of the product may remain in the packaging at the end of the product's lifecycle and so the amount and fate of this residual product is relevant to the ESD.

2.6 Bulk storage of chemicals

A number of methods are used for the bulk storage of chemicals within the EU. These are discussed in detail in European Commission (2004).

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[11] See http://www.ukpia.com/industry_issues/environment_air_quality_health_safety/health_and_safety/safe_storage_and_use_of_fuel.aspx?moduleid=24798&forcenativeview=true.

In volume terms, the largest storage capacities for liquids are associated with oil refineries, and this is the area for which the largest amount of information appears to be available. Within the UK there are currently nine main refineries, out of a total of around 100 in Europe (UKPIA, 2004). The refineries are situated around the coast of the UK for ease of crude oil tanker access. Large-scale storage is carried out at the refineries themselves, but also at storage terminals close to major conurbations. The methods used for transportation include pipeline networks, rail, ship and road, and around 77 million tonnes of petroleum products are transported around the UK each year. The use of modern floating roof storage tanks, coupled with vapour recovery from tanks and loading gantries, means that the fuel distribution industry is increasingly becoming a closed system.

Within the United Kingdom, a large amount of legislation covers the storage of chemicals (relating to both health and safety and protection of the environment). Legislation for England is summarised in CIRIA (2003) and relevant legislation is included in Appendix B of this report. Similar legislation will also apply in many cases for Wales, Scotland and Northern Ireland.

2.6.1 Types of bulk storage tanks for liquids and liquefied gases

This section considers possible storage tanks for liquids. The storage tank itself provides the primary containment system for liquids. However, bunding (a system of containing walls or embankments, also known as dikes) and other secondary containment systems are usually present at the storage site in case of failure (leakage) of the primary containment system when the storage tank is above ground. The main types of system typically used are as follows (CIRIA, 2003; Environment Agency, 2004a):

- Local containment – this consists of a bunded area around the primary storage system.
- Remote containment – this consists of a collection system (such as low surrounding bund and/or drainage network) around the primary storage system from which any spills are transferred (by gravity or pump) to a distant containment system. Such systems are used in situations where the area surrounding the primary containment system is not large enough for local containment, or where the primary storage is located on a sloping site.
- Combined containment – this is similar to remote containment, but a substantial proportion of the storage of the containment system is within the local bund.
- Dedicated containment drains – these can be used in situations where bunds cannot be constructed (for example, where vehicular access is required). They may also be used across building doors/entrances and in tanker loading or storage areas.

The size of the secondary containment system should be sufficient compared with the volume of the primary storage capacity, and should also allow for rainfall, fire-fighting foams (in the case of fires) and so on (CIRIA, 2003; Environment Agency, 2004a).

Within the United Kingdom, the Department for Environment, Food and Rural Affairs (Defra) has published a code of practice related to the protection of groundwater from solvent use and storage (Defra, 2004). This code of practice outlines measures and procedures that can be used to minimise contamination of groundwater from leaks and spills during the delivery, handling and storage of solvents at a site. Similarly, the Environment and Heritage Service, Scottish Environmental Protection Agency and the Environment Agency have published pollution prevention guidelines to minimise pollution from above ground oil storage tanks (Environment Agency, 2004a) and the storage and handling of drums and IBCs (Environment Agency, 2004b).

2.6.1.1 Open top storage tanks

This type of storage tank is open to the atmosphere. The tanks are normally made from curved steel panels or concrete sections and are generally used for storing manure slurry (European Commission, 2004). This type of storage tank is of limited relevance to this ESD.

2.6.1.2 External floating roof tanks (EFRT)

These types of tanks typically consist of an open-topped cylindrical steel shell equipped with a roof that floats on the surface of the stored liquid (European Commission, 2004). The roof rises and falls as the volume of liquid increases and decreases. The roof is fitted with a rim seal in order to reduce emissions to the air. There are three main types of floating roof: a) pontoon-type floating roof, b) double-deck floating roof and c) special buoy-type and radially reinforced roof. A dome roof can also be fitted on this type of tank in order to prevent water ingress.

2.6.1.3 Vertical fixed roof tanks (FRT)

Fixed roof tanks can either operate at atmospheric pressure (free vented), low pressure (up to 20 mbar internal pressure) or high pressure (up to 60 mbar internal pressure) (European Commission, 2004). Both low pressure and high pressure tanks are equipped with pressure/vacuum relief valves (PVRVs). Such tanks may also contain a blanket of an inert gas (such as nitrogen) in the vapour space above the liquid for safety reasons.

2.6.1.4 Above ground horizontal atmospheric storage tanks

Horizontal fixed roof storage tanks generally have a capacity of $\leq 150\ m^3$ (European Commission, 2004). They can be constructed from steel, steel with a fibreglass overlay or fibreglass-reinforced polyester. They are usually equipped with PVRVs, gauge hatches, sample wells and manholes to provide access.

2.6.1.5 Horizontal pressurised storage tanks

Two main types of horizontal pressurised storage tanks are in general use (European Commission, 2004). These are termed low pressure (170-1,030 mbar) and high pressure (>1,030 mbar). They are generally used for storing organic liquids and gases with high vapour pressures, for example butane. Many sizes of horizontal pressurised tanks are available but they are generally bullet or spherical in shape.

2.6.1.6 Vertical pressurised storage tanks

These are similar to the horizontal tanks but tend to be used where space is limited and/or a large capacity tank is not required. Normally, vertical tanks are limited to a maximum size of around 10 metres diameter and 25 metres height (capacity 1,750 m^3) for economic reasons (European Commission, 2004).

2.6.1.7 Spheres (pressurised)

These are again similar to the horizontal and vertical pressurised tanks but they generally have a larger capacity; up to 3,500 m^3 is the practical upper limit (European Commission, 2004).

2.6.1.8 Mounded storage (pressurised)

Mounded storage refers to the pressurised storage of liquefied petroleum gases at ambient temperatures in horizontal cylindrical tanks at or just below ground level, but completely covered with a suitable backfill (European Commission, 2004). A 'mound' may contain several tanks side-by-side. A tank diameter of eight metres is considered to be the practical upper limit for the tank size, giving a maximum volume of around 3,500 m^3.

2.6.1.9 Variable vapour space tanks

This type of tank is fitted with expandable vapour reservoirs to allow for vapour volume fluctuations as a result of changes in ambient temperature and atmospheric pressure (European Commission, 2004). Two types of variable vapour space tanks are commonly used.

Lifter roof tanks are used to store liquid products and have a telescoping roof that fits loosely around the outside of the main tank wall, with the space between the roof and wall being sealed using either a wet seal (a trough filled with liquid) or a dry seal (flexible coated fabric) (European Commission, 2004). This type of tank is rarely used in Europe for storing petroleum products.

The other type of variable vapour space tank used is a flexible diaphragm tank (European Commission, 2004). This is used only to store vapours at, or very close to, atmospheric pressure and is usually connected to a series of other tanks in order to reduce breathing emissions from these tanks.

2.6.1.10 Refrigerated storage tanks

Three main types of refrigerated storage tanks are used (European Commission, 2004).

Single containment tanks consist of either a single or double wall constructed so that only the containing wall in contact with the product needs to meet any low temperature requirements (European Commission, 2004). The function of the outer wall (if one is present) is primarily for the retention and protection of insulation rather than for containment of product leakage from the inner tank.

Double wall containment tanks are designed so that both the inner tank and outer shell are capable of containing the liquid product stored (European Commission, 2004). The liquid is stored in the inner tank but the outer shell is able to contain any liquid product (though not vapour) leakage from the inner tank.

Full containment tanks are designed so that both the inner and outer tanks are capable of containing the refrigerated liquid stored (European Commission, 2004). In this case the outer tank is able to contain both liquid and vapour leaks from the inner tank.

Refrigerated storage is usually used for the large-scale storage of liquefied gases such as ammonia and chlorine.

2.6.1.11 Underground horizontal storage tanks

Underground (buried) horizontal storage tanks typically have a capacity of less than 50 m^3 and are made of steel or fibreglass reinforced polymers (European Commission, 2004). They are frequently used for the storage of gasoline, diesel and other fuels at the point of use.

Storage at fuel filling stations is in underground tanks. There were 9,764 filling stations in the United Kingdom at the end of 2005 (Energy Institute, 2006).

Within the UK, Defra has published a code of practice on the protection of groundwater from petrol stations and other fuel-dispensing facilities involving underground storage tanks (Defra, 2002). This code of practice outlines measures that can be used to minimise contamination of groundwater from leaks and spills from petrol stations. Similar codes of practice on fuel storage and distribution in general are published by the Energy Institute[12] (formerly the Institute of Petroleum), for example, Energy Institute (2005). Process guidance notes have also been published on the unloading of petrol into storage tanks at petrol stations (Defra, 2004b) and storage, unloading and loading of petrol at terminals (Defra, 2004c). There is also a Health and Safety Eexecutive (HSE) Approved Code of Practice covering the unloading of tankers at filling stations (HSE, 2003).

2.6.1.12 Basins and lagoons

Within the chemicals industry, basins and lagoons are most commonly used to hold various types of water such as cooling water, fire-fighting water, untreated waste water and treated water or brine (European Commission, 2004). Basins and lagoons are also used in agriculture for storing and treating manure and silage.

As basins and lagoons are not used directly for the storage of chemicals they are of limited relevance to this ESD.

2.6.1.13 Caverns

Various types of caverns are used for the storage of hydrocarbon products. These are discussed below. However, systems generally tend to be quite specialised and used for longer term storage and so emissions from this type of storage are not considered further in the ESD.

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[12] A full list of the available codes and guidance published by the Energy Institute can be found at http://www.energyinst.org.uk/index.cfm?PageID=691.

Mined caverns (atmospheric)

Mined caverns are used for storing hydrocarbon products that are less dense than water (European Commission, 2004). Two main types of mined caverns are used for storage, those with a fixed water bed and those with a fluctuating water bed. Injection of cement onto the roof and walls of caverns can help minimise the amount of seepage water into the cavern.

Caverns with a fixed water bed contain a layer of water (usually less than one metre deep) which is kept at a constant level with a pump pit weir (European Commission, 2004). Such caverns are used for the storage of crude oil, liquefied petroleum gas, gasoline, diesel fuel, light fuel oil and heavy fuel oil.

In caverns with a fluctuating waterbed, the level of water in the cavern is allowed to vary to keep the level of hydrocarbon stored at a constant height, so that the cavern is always full (European Commission, 2004). This type of cavern is used to store gasoline.

Typical volumes for storage caverns range from 50,000 to 580,000 m^3. The depth of the cavern varies according to the presence of suitable rock and the hydrocarbon product stored. Typical depths range from 40 to 170 metres.

Mined caverns (pressurised)

Most mined caverns are of the pressurised type. These are set at such depth that the static head of the water table surrounding the cavern is higher than the pressure of the stored hydrocarbon product. This creates a pressure gradient towards the inside of the cavern which prevents leakage of the product into the rock strata (European Commission, 2004). The caverns are usually designed and operated in such a way that any hydrocarbon vapour condenses into a liquid during filling, thus avoiding any pressure rise in the cavern and potential release to the atmosphere.

The sizes of, and products that can be stored in, pressurised mined caverns are similar to those in atmospheric mined caverns (see Section 0), but they can also be used to store pressurised liquefied gas. However, pressurised mined cavern storages can be as small as 8,000 m^3 for liquefied petroleum gas.

Salt leach caverns

Salt leach caverns are formed by drilling a well into the salt formation, circulating fresh or low salinity water into the well and withdrawing the brine from the cavern (European Commission, 2004). This type of cavern can be used for the storage of liquid hydrocarbons and liquefied pressurised gases. The caverns are filled by pumping the hydrocarbon product into the upper part of the cavern. This displaces the brine (which undergoes a decanting or degassing process and is stored in a lined pond or lagoon) and the hydrocarbon product is then stored under pressure above a brine solution (the static weight of the brine and the hydrocarbon itself creates the pressure). The product is generally discharged by pumping brine back into the cavern or, in the case of shallow caverns, by means of submerged pumps. The salt provides an impermeable seal to the cavern walls.

Salt caverns are typically formed at depths of 300-1,200 m and have a typical volume of 90,000-450,000 m^3. However, more than one cavern may be used at a given site. For example, a site in France has a total of 26 storage caverns for crude oil, diesel oil, gasoline and naphtha, giving a combined storage volume of around six million m^3 (European Commission, 2004).

2.6.1.14 Floating storage

Ships can sometimes be used to provide additional temporary storage capacity at marine terminals (European Commission, 2004).

2.6.1.15 Storage of packaged chemicals

The European Commission (2004) indicates that the main types of containers used to store (and transport) chemical products are as follows:

- glass bottles up to five litres;
- plastic bottles or drums up to 60 litres;
- metal canisters up to 25 litres;
- steel or glass-fibre reinforced polyester (GRP) drums up to 300 litres;
- paper or plastic bags;
- IBC.

Storage of containers holding dangerous materials is considered in European Commission (2004). The main types of storage used include:

- loose cabinets;
- fitted cabinets;
- storage cells in a multi-storey building;
- storage cells in a single-storey building;
- storage buildings;
- storage yards.

Cabinets are used for the small-scale storage of chemicals. Storage cells for hazardous materials are normally located on the ground floor of a building (European Commission, 2004). A storage cell in a multi-storey building will normally contain a maximum of 500 litres of hazardous material, whereas a storage cell in a single-storey building will normally contain a maximum of 2,500 litres of hazardous material. Storage cells may contain loose or fitted cabinets for the separate storing of incompatible hazardous materials within the area.

Storage buildings can be stand alone buildings or be part of another building (European Commission, 2004). They are used to store a wide range of container types and substances, including drums with flammable liquids, cylinders of pressurised gas, packaged chemical products and chemical wastes awaiting disposal.

Outside storage yards can also be used to store chemicals (European Commission, 2004). The yards are often equipped with a roof to protect the stored products from exposure to direct sunlight or rain. When the storage area is not covered with a roof, provisions for the controlled discharge of rainwater are normally in place.

The potential for emissions from packaged goods during storage appears to be low. Some packed chemicals may have vented caps (for example, aqueous ammonia and aqueous HCl) and this could potentially lead to emissions to air if the packaging is allowed to heat up to too high a temperature. In addition, it is possible that the caps may leak if the packaging is mishandled and laid on its side (the packaging, however, will always have arrows showing the correct way up for storage). With these exceptions, emissions from storage of packaged chemicals are likely to be low.

2.6.2 Storage systems for bulk solids

2.6.2.1 Open storage

Storage heaps (either indoors or outdoors) are used for storing larger quantities of bulk materials (European Commission, 2004). Open storage is usually used for materials such as coal, gypsum, ore, scrap and sand, which are not seriously affected by exposure to weather.

Heaps are typically constructed using tipper trucks, wagons or belt dischargers (conveyor belts which throw bulk material over the heap) (European Commission, 2004). The substance can be removed from the heap using back-loading devices such as bridge scrapers, lateral scrapers and portal scrapers.

2.6.2.2 Silos and bunkers

Silos are made of concrete, metal or plastic. Concrete silos can be up to tens of thousands of tonnes capacity, but metal and plastic silos tend to be much smaller than this. Silos are normally used for the storage of dry and/or fine materials such as cement and grain. Bunkers are normally used for the storage of coarser materials. Both silos and bunkers can be open-topped or closed-topped.

2.6.2.3 Sacks and bags

Sacks and bags are used where the quality of the stored product is important (European Commission, 2004).

2.6.2.4 Storage of packaged chemicals

Packaged solid chemicals are stored in the same facilities as liquid chemicals (see Section 0).

2.7 Transfer and handling of chemicals

Various systems are used for the transfer and handling of chemicals.

2.7.1 Systems for bulk liquids and liquefied gases

2.7.1.1 Above ground closed piping transfer systems

These systems are the most common type within large-scale storage facilities and are designed to transport liquids, refrigerated liquefied gases, pressurised liquefied gases or vapours. Emissions from this type of system generally only occur as a result of leakage through seals and/or cleaning and purging operations (European Commission, 2004). The piping system may contain a relatively small number of valves and fittings compared to industrial chemical production systems.

2.7.1.2 Above ground open piping transfer systems

These systems are used to collect either rainwater or spillage and prevent these from polluting the subsoil or surface water by gravity drainage to a central collection pit (European Commission, 2004). Examples of such systems include gutters, open drains and drip pans around pumps. This type of system is of limited relevance to the ESD.

2.7.1.3 Underground piping transfer systems

These systems are normally designed to transport liquids, refrigerated liquefied gases, pressurised liquefied gases or vapours (European Commission, 2004). The piping system usually consists of fully welded pipeline with only a limited number of valves and fittings. Emissions from this type of system generally only occur as a result of leakage through seals and/or cleaning and purging operations.

2.7.1.4 Loading and unloading of transporters

Transporters (such as road tankers, rail tankers and ships) are loaded and unloaded by a flexible hose or a loading arm (these are fitted with sealed swivel joints to allow the connection to move) (European Commission, 2004). Any vapours displaced during liquid loading can be collected, if necessary, through pipework fitted on the transporter or through modified loading arms.

The type of vapour collection system used depends on whether the tanker is top-loaded through an open hatch or loaded through fixed pipework on the tanker. For top-loading, vapours can be collected with special loading arms that seal against the loading hatch. Tankers with fixed pipework require vapour vent valves from which the vapour can be collected at the loading facility.

Some ships (particularly chemical tankers) are fitted with vapour collection pipework systems; however, most general purpose petroleum product carriers operating in EU waters do not have vapour collection systems (European Commission, 2004).

2.7.2 Systems for bulk solids

2.7.2.1 Grabs

Grabs are used for the large-scale loading and unloading of bulk materials. The capacity of a grab is generally limited to around 2,000-2,500 tonnes per hour. Grabs are typically used for transport of a substance from ship to ship, ship to storage and/or wagon and from storage to processing plants. Further transport of the material is usually by belt conveyor. Grabs can be used for nearly all bulk materials (European Commission, 2004).

2.7.2.2 Discharge hoppers

Discharge hoppers are used to transfer the substance from grabs or belts to the load area of a vehicle, onto another conveyor system or into a storage system. They are used, for example, in the loading and unloading of bulk materials in ports and are suitable for handling a wide range of bulk materials such as grain, fertilisers, coal, non-iron metal ores or concentrates and raw materials for the cement industry (European Commission, 2004).

2.7.2.3 Tubs

Tubs are transportable vessels with at least one gate and they can be used to load as well as transport products, though they are not normally used with dusty products. They are normally filled from the top.

2.7.2.4 Suction air conveyors

Suction air conveyors are pneumatic systems that transport the material in closed pipes using streaming air (European Commission, 2004). In the system, the material is sucked up by a nozzle and is transported under vacuum to a separator, where the conveyed material is discharged (in most cases over cell-wheel gates) and transferred on to a continuous conveying system. Such systems are generally used for unloading ships, wagons and trucks and are suitable for bulk materials with specific densities < 1.2 g/cm^3 (for example grain, aluminium oxide, petroleum coke, cement, limestone, lime and clay, potash, sodium sulphates and similar chemicals, fertilisers, salt and some plastics). Both stationary and mobile systems may be used. The throughput of the system depends on the material being conveyed; for example, a throughput of 500-600 tonnes per hour is typical for grain and a throughput of 1,000 tonnes per hour is typical for a substance such as aluminium oxide. These systems are used in many industries including agriculture, mining, chemicals and food industries.

2.7.2.5 Excavators and frontloaders

Excavators and frontloaders are mobile loading devices that are typically used for a number of operations, for example to work on small heaps, to load vehicles, to transport material to bins or boxes, to feed hoppers and to trim the material in ships (European Commission, 2004).

2.7.2.6 Wagon and truck emptying

Rail wagons and road trucks are typically used to transport grain, fertiliser, coal, sand and ores (European Commission, 2004). They are normally loaded via grabs, loading pipes or conveyor belts. Unloading is usually carried out via lateral discharge openings or at the bottom of the wagon/truck. Unloading stations are normally roofed or partly enclosed. Unloading generally occurs onto conveyor belts or bands or, in the case of lateral discharge wagons/trucks, via special gutters to the next handling device. At ports, it is common to unload the wagons/trucks onto belts, where the material is conveyed either to a subsequent means of transport (for example a ship or truck) or to a storage system.

2.7.2.7 Fill pipes

Fill pipes (also known as loading pipes or down pipes) are used to load containers, trucks, trains and ships (European Commission, 2004). They are available as a rigid pipe or as a vertical and/or horizontal movable pipe. The material is fed to the top of the pipe (usually by conveyor) and then falls through the pipe under gravity into the container.

2.7.2.8 Fill tubes

Fill tubes (also known as loading tubes) consist of an inner and outer tube made of plastic or of a tough woven plastic textile. They can be used for open loading of bulk materials into trucks, ships or heaps, or for the closed loading of bulk materials into silo trucks or containers; for closed loading, a cone is fixed to the end of the tube so that dust cannot be emitted (European Commission, 2004).

2.7.2.9 Cascade tubes

Cascade tubes are similar to fill tubes but incorporate a cascade to reduce the fall height within the tube. This results in much lower dust formation and more careful treatment of the material during loading. The tubes are coated with high density polyethylene, sintered aluminium, ceramic brick or steel in order to resist abrasion. Cascade tubes can be used to load containers, silos, trucks, wagons and ships, and can also be used for transfer between conveyor belts. They can be used for bulk materials such as potash, phosphate, grain, coal, coke, aluminium oxide, cement, sodium phosphate, maize and animal feed. Throughputs of 30-5,000 m^3/hour can be achieved (European Commission, 2004).

2.7.2.10 Chutes

Chutes are suitable for non-caking materials and dry operations, but are not suitable for fine powdery materials. They are used as loading devices or for transfer between two conveyors. Rigid and moveable chutes are available (European Commission, 2004).

2.7.2.11 Thrower belts

Thrower belts are short rubber conveyor belts that are used in situations where the main conveyor or loading system cannot be installed close enough to the required discharge point.

2.7.2.12 Belt conveyors

These are the most common continuous conveyor systems used. Various types of belt conveyors are available (European Commission, 2004).

In conventional belt conveyors, the belt is concave in shape and the material is transported on the top of an endless rubber belt. Belt speeds of roughly 60 metres per minute to 300 metres per minute are typical.

Steep belt conveyors are similar to conventional ones but the band contains profiles or small side-belts to allow materials to be transported up slopes.

Hanging belt conveyors (also known as loop belt conveyors or tube belt conveyors) are relatively new and not in common use (owing to the high cost). These are an adaptation of conventional conveyors where, after the material has been fed onto the belt, the belt is rolled into a closed tube so that the material being conveyed is protected inside the tube. The tube is unrolled at the discharge point. Such belts are used for applications that require transport over long distances or up steep inclines such as in mines, iron and steel works, cement, fertiliser, food and chemicals industry. Examples of materials conveyed in such systems include ores, coal, coke, limestone, broken stones, cement, gypsum, copper ore concentrate, ash and salt. The belt speeds are in the range 60 metres per minute to 300 metres per minute.

Double belt conveyors consist of two conveying belts, a support or carry belt and a cover belt. These systems are suitable for materials with a generally even particle size (ranging from fine to coarse) but not for powdery, lumpy materials or those that tend to cake onto the belts.

In folding belt conveyors, the belt is folded around the product so that it is completely enclosed. For the zipper conveyor, the edges of the belt are connected via a zipper, again resulting in the material being completely enclosed within the belt.

2.7.2.13 Bucket elevator

These consist of buckets that are fixed to a drive mechanism such as a chain or conveyor belt (European Commission, 2004). They are generally used for vertical transport but are also used as continuous ship unloaders to convey material horizontally and vertically in the same system. Bucket elevators can be used for bulk materials ranging from powders to substances with particle sizes up to 60 mm, such as flour, corn and pulses, sand, coal, limestone, cement or ash. The maximum throughput of such systems is around an average of 3,000 tonnes per hour and a peak of 4,000 tonnes per hour. The elevator itself is encased and can be fitted with a suction system to limit dust emissions.

2.7.2.14 Chain conveyors

Several types of chain conveyors are in use (European Commission, 2004). These include trough chain conveyors and scraper conveyors. In trough conveyors, the chain is run through an enclosed trough into which the material is fed. They are typically used in bunkers and silos for loading and unloading materials such as grain, oil seed, food and animal feed, coal, cement, chemical products and minerals. Throughputs of 10 to 2,000 m^3 per hour can be achieved.

Scraper conveyors are mainly used for feeding and reclaiming heaps of ore, coal and salt.

2.7.2.15 Screw conveyors

Screw conveyors are suitable for conveying very dusty materials and are used for materials such as aluminium oxide powder, cement, grain, gypsum, fertilisers, coal, lime and phosphates (European Commission, 2004). In the system, the material is driven through a trough or pipe by means of a rotating conveyor worm. They can operate horizontally or up to a slope of 30°. The maximum throughput is 1,000-1,200 tonnes per hour.

2.7.2.16 Pressure air conveyors

These are similar to suction air conveyors (see Section 0) except that air is blown through the system rather than sucked through the system (European Commission, 2004). The material is introduced into the system by a feed mechanism (cell-wheel gate, screw or feed hopper). These conveyors are suitable for fine particle crystalline bulk materials such as cement, lime or gypsum.

2.7.2.17 Feeders

The feed and discharge points are usually the most significant in terms of dust formation (and hence release to the environment) from conveyor systems. Several types of systems are in use such as belt feeders, roll feeders, screw feeders, rotating wheel disclaimers and rotating feeders (European Commission, 2004).

Belt feeders are essentially rectangular hoppers which channel the bulk material from an overhead storage unit onto the conveyor system. Enclosed hopper systems are available, some of which may incorporate suction or sprinkling systems to minimise dust formation.

Roll feeders are rotating rollers fitted to the openings of bunkers or silos. The rollers feed the material onto a conveyor system.

Screw feeders are similar in operation to screw conveyors (see Section 0).
Rotating wheel disclaimers and rotating feeders are used to feed material from bunkers and silos to conveyor belts. Rotating feeders contain cells with lamellae on a rotating axis enclosed within a cylinder with openings at the top and bottom. Material is fed into the top from the silo or bunker and out of the bottom to the conveyor system. In rotating wheel disclaimers, the material is fed from the storage system to a bevelled ground plate in a discharge slot. A rotating bucket wheel then removes the material from the outlet of the slot into the conveyor system.

2.7.3 Transfer and handling of packed goods (bags, drums, IBCs)

Several different methods are used for filling of bags, drums and IBCs, some of which can be automated. For example, modern bag-filling equipment is designed to feed a predetermined weight or volume of product into the bag either by gravity feed, auger feed, conveyor-belt feed, centrifugal belt feed, impeller feed or fluidized bed feed. Common filling equipment used for solids with IBCs include a filling head, a vacuum transfer system and a totally sealed system. Further details of the various filling systems that are used are given in Section 0.

Small containers (containing up to around 25 litres or 25 kg) can be readily emptied by hand (European Commission, 2004). Emptying of the contents of larger containers (for example 210 litre drums and IBCs) can be achieved by gravity or by using a pump.

For some liquids (such as chlorinated solvents), a portable tank on wheels or a skid may be used (European Commission, 2004). Such units are normally exclusively used for solvent transfer and contain an integral pump and drip tray.

Several methods can be used to empty solids from IBCs (Semenenko, 1992). Manual discharge involves simply opening a valve in the IBC outlet, which then allows the material to discharge into an opening or chute and into the subsequent processing equipment. For IBCs equipped with a side outlet (such as hinged flap or door), the IBC can be lifted onto a frame which then tilts the IBC to around 45° to allow the material to discharge. Both manual discharge methods require the use of a dust collection system to minimise dust emissions to the environment.

Semi-automatic and automatic discharge of IBCs are also possible, but require the use of a discharge station and IBCs specifically designed to fit the station.

The opening of sacks and bulk bags containing dusty material is usually carried out in specialised installations with suitable suction equipment.

2.8 Choice of material for transport and storage system

It can be seen from the preceding sections that a number of materials can potentially be used in the manufacture of transport or storage systems. The choice of material is usually dependent on the properties of the chemical being transported or stored. CIRIA (2003) provides general guidance on the chemical compatibility of various materials used for the manufacture of transport or storage systems. This is summarised below.

Carbon steel – this is compatible with a large number of chemicals but may react with ,for example, dilute acids. It is also susceptible to corrosion by oxygen and water, which is exacerbated by aggressive conditions (such as a saline environment or elevated temperatures).

Stainless steel – this is less susceptible to corrosion by oxygen/moisture than carbon steel, but may still corrode in saline environments. The corrosion resistance is dependent on the grade of stainless steel used. Stainless steel tends to be used where the quality of the stored chemical is the prime consideration.

Alloys and ‘exotic’ metals – the most common metal under this category is aluminium. These metals can be used for storage of chemicals where steel-based metals are not suitable.

Plastics – these are used for chemicals that are aggressive to, or react with, steel. They are also used as an economic alternative to steel. With the appropriate choice of the plastic, containers that are compatible with most chemicals can be made. Plastic containers are, however, susceptible to degradation by ultraviolet (UV) light and so would normally contain UV stabilizers. The lifetime of plastic tanks and containers is affected by the fill/empty cycle frequency.

Multiple material systems – these include plastic-lined steel components and carbon steel tanks with stainless steel base plates. These systems combine the strength of steel with the chemical compatibility/corrosion resistance properties of other materials.

Coatings, linings and protection systems – as well as the basic materials outlined above, components of storage systems can be surface-coated or lined for added corrosion protection or to prevent attack on the container wall by the contents. Cathodic protection systems can also be used to prevent corrosion of storage tanks (although such systems cannot be used when the tank is situated on bitumen/sand or other similar surfaces).

3. EMISSION FACTORS FOR TRANSPORT AND STORAGE EQUIPMENT AND SYSTEMS

This section brings together published emission factors from a number of sources which were located in the course of the production of this document. The coverage may not be comprehensive, and there may be other factors available from other sources. The factors here are reported for information, and are not necessarily recommended for use in Section 5.

3.1 Identification of the potential points of release during transport and storage of chemicals

The filling and emptying of containers can result in emissions to air (such as vapour or dust) and potentially soil and water (through leaks and drips).

For most chemicals, the potential for release to the environment is highest during the transfer of chemicals to and from transport and storage systems. As discussed in Section 0, a number of methods are used for the transfer of chemicals to and from tankers, storage tanks, containers and so on. The controls applied to the transfer process will be different depending on the container being filled or emptied, and the type of chemical being transferred. These sources of emission are discussed below in relation to the different types of storage, tanker or container for different types of chemicals (such as solids, volatile liquids, viscous liquids).

Along with the transfer process, several other sources of emissions exist. These are related to the storage of liquids in tanks, solids in open storage, pipelines, washing and cleaning of tankers and containers., recycling of packaging and disposal of packaging.

The potential sources of emissions from a number of transport and storage systems are discussed in European Commission (2004). These sources are summarised in Appendix C.

3.2 Filling

3.2.1 Road tankers

Several methods of filling road tankers can be used. In simple terms, they can be filled either from the top (known as splash loading) or from the bottom (submerged loading), with different degrees of containment (such as vapour recovery systems). Bottom loading is standard practice for the oil industry.

Vapour balancing can be used for both the loading and unloading of road tankers (European Commission, 2004). During filling of the tanker, the vapours displaced from the tanker are collected through pipework and carried back to the storage tank from which the product is being transferred. Emission reductions of greater than 95 per cent have been reported using this system. Vapour balancing is only possible when loading from non-pressurised fixed roof-type storage tanks.

It should be noted that vapour balancing results in higher concentrations of vapour being present in the empty tanker. This vapour may be emitted when the tanker is refilled unless a vapour balancing system is again used.

Many viscous or (semi-)solid products may be heated to facilitate filling of the tanker.

Published emission factors for losses during filling of tankers are summarised in Table 0.1.

Table 0.1 Emission factors for losses during filling of tankers

Chemical type	Emission factor	Emission media	Comment	Reference
Gasoline - unleaded	0.05 kg NMVOC/tonne	Air	Factor given for road and rail tanker loading at refineries.	NAEI, 2000
	0.07 kg NMVOC/tonne	Air	Factor given for tanker loading at petrol terminals.	NAEI, 2000
Gasoline - leaded	0.05 kg NMVOC/tonne	Air	Factor given for road and rail tanker loading at refineries.	NAEI, 2000
	0.07 kg NMVOC/tonne	Air	Factor given for tanker loading at petrol terminals.	NAEI, 2000
Gasoline	1.43 kg VOC/m^3 1.94 VOC/tonne	Air	Splash loading	WHO, 1993
	0.59 kg VOC/m^3 0.80 kg VOC/tonne	Air	Submerged loading – normal service	WHO, 1993
	0.98 kg VOC/m^3 1.33 kg VOC/tonne	Air	Submerged loading – vapour balance[a]	WHO, 1993
	0.05 kg VOC/m^3 0.07 kg VOC/m^3	Air	Vapour-controlled loading	WHO, 1993
Jet naphtha loading	0.43 kg VOC/m^3 0.58 kg VOC/tonne	Air	Splash loading	WHO, 1993
	0.18 kg VOC/m^3 0.24 kg VOC/tonne	Air	Submerged loading – normal service	WHO, 1993
	0.30 kg VOC/m^3 0.40 kg VOC/tonne	Air	Submerged loading – vapour balance[a]	WHO, 1993

Note: a) In the vapour balance method of loading, the tanker receives the vapours displaced during the subsequent filling of the storage tank. According to WHO (1993) this increases the concentration of the chemical in air within the empty truck and this causes a higher emission when the tanker is refilled.

3.2.2 Rail tankers

No published emission factors have been found for the filling of rail tankers. The process is, in principle, similar to the filling of road tankers and so it would be expected that similar sources of emission exist.

3.2.3 Ship tankers

Published emission factors for losses during the filling of barges and ships are summarised in
Table 0.2.

In principle, the use of vapour balancing techniques is possible when filling ships and barges; however, it has been reported (European Commission, 2004) that only a limited number of general purpose seagoing tankers are fitted with the necessary vapour collection pipework.

Table 0.2 Emission factors for losses during filling of tankers

Chemical type	Emission factor	Emission media	Comment	Reference
Gasoline	0.41 kg VOC/m^3 0.55 kg VOC/tonne	Air	Barges	WHO, 1993
	0.215 kg VOC/m^3 0.291 kg VOC/tonne	Air	Ships and ocean barges	WHO, 1993
Crude oil	0.12 kg VOC/m^3 0.137 kg VOC/tonne	Air	Barges	WHO, 1993
	0.073 kg VOC/m^3 0.083 kg VOC/tonne	Air	Ships and ocean barges	WHO, 1993
Jet naphtha	0.15 kg VOC/m^3 0.20 kg/tonne	Air	Barges	WHO, 1993
	0.06 kg VOC/m^3 0.08 kg VOC/tonne	Air	Ships and ocean barges	WHO, 1993
Cement	0.1 kg/tonne clinker	Air	Factor is for bulk loading – the actual transport system used was not stated	WHO, 1993

3.2.4 Trucks

In contrast to tankers, less information is available on the emissions from loading trucks. Trucks are mainly used for transport of bulk products such as ores and minerals or packaged goods. Emissions to air could potentially occur from the loading of bulk products, but emissions from loading of packaged products are expected to be minimal.

The World Health Organisation (WHO 1993) gives an emission factor to air of 0.17 kg total suspended particulates (TSP) per tonne for truck loading by conveyor and 29 kg TSP per tonne for truck loading by front-end loader during stone quarrying. This latter value appears to be high, but no further details on the source of this value were found.

3.2.5 Drums

Emissions of vapours and dust may occur during the filling of drums. No emission factors for the process have been found in the literature, and limited information about filling methods is available. Open-headed plastic drums have a variety of cover styles to accommodate filling requirements, and some fibre drums are designed with a full open top to allow quick filling. In addition, emissions can potentially occur from overfill and spills. However, the use of automated filling equipment, along with secondary containment systems, should minimize the emission to the environment for overfill and spills.

The Environment Agency (2004b) provides guidance on minimising environmental releases from the storage and handling of drums. Recommended containment methods include bunds, kerbs, drip trays or any other system that will prevent a spilled product escaping. The system chosen will depend on the quantities and nature of materials stored, on-site facilities and operational needs. Drip trays are ideal for single drums in storage or at their point of use. Spill kits containing materials such as leak-sealing putty, over-drums, drain seals, oil or chemical absorbents and personal protective equipment should be available on site, and all staff should be trained in the use of this equipment.

3.2.6 IBCs

Similar to drums, emissions of vapours and dust are likely to occur during the filling of IBCs. No emission factors for the process have been found in the literature.

Common filling equipment used for solids with IBCs includes a filling head, a vacuum transfer system and a totally sealed system (Semenenko, 1992).

A filling head consists of a round metal fitting linked by a flexible connector to a bulk storage vessel or process equipment. The filling head can also include an internal ultrasonic level indicator, and a dust collection collar can also be fitted that connects the filling head to a dust collection system to extract displaced air from the IBC. In addition, the area around the filling station is also typically equipped with a dust collection system, to prevent dust emissions to the environment when the filling head is connected or removed. During filling, the filling head would typically be in direct contact with the inlet on the IBC, but for gravimetric gain-in-weight filling, the head can be located in a non-contact position. Filling stops when the level indicator (or load cell system in a gravimetric application) indicates that the IBC is full. A filling head is typically used with non-toxic, non-hazardous materials that do not require a high level of dust containment.

In the vacuum transfer system, the source of the material (such as bulk storage, a drum, or process) is connected to the IBC via a pneumatic conveyor. The IBC is located below the outlet (termed vacuum transfer head) from the conveyor. A vacuum receiver with bag filters is located above the vacuum transfer head. In use, the vacuum source draws material from the drum or process into the vacuum receiver, which separates the material from the air and discharges the material through the vacuum transfer head into the IBC inlet. The receiver filters the process air and exhausts it. The conveyor components and the bag filters may need to be cleaned between batches in order to prevent cross-contamination.

Another type of vacuum system, termed the reverse-pulse vacuum transfer system, may also be used. In this case, a vacuum is drawn through the IBC and the material is conveyed from the drum through a valve directly into the IBC. The vacuum source is protected from contamination with the solid by a series of bag filters and valves. The system essentially isolates the IBC and material source from the vacuum source while keeping the IBC under vacuum. The filters can be cleaned into the IBC by reverse-pulse cleaning methods.

Similar to the case of filling heads, both the conventional and reverse-pulse vacuum transfer systems require the area around the filling station to be equipped with a dust collection system, to prevent dust emissions to the environment when the filling equipment is connected or removed. The types of materials that can be handled by vacuum transfer systems are similar to those that can be handled with filling heads.

Dust-tight filling systems are available for a range of IBCs, and standard or high containment options are available. Standard filling systems may be engaged to the inlet of the IBC manually or automatically.

Flexible IBCs are preferably filled with the base of the bag supported by a pallet and the body of the bag supported by the top lift device. The top inlet should be closed properly and the liner inflated prior to filling. If the flexible IBC has a discharge spout, it should be tied off or closed before filling.

Totally sealed filling systems eliminate the need for dust collection equipment, as a continuous seal is made between the bulk storage vessel and the IBC. The potential for emissions to the environment from such systems is therefore very small. These systems are particularly suited to handling substances such as highly active pharmaceuticals and toxic chemicals.

Similar to the case with drums, the Environment Agency (2004b) provides guidance on minimising emissions to the environment during the handling and storage of IBCs. Again, containment methods include bunds, kerbs, drip trays or any other systems that will prevent a spilled product escaping are recommended.

3.2.7 Bags

Bags are used for solids and so dust emissions may occur during filling. Modern bag filling equipment is designed to feed a predetermined weight or volume of product into the bag (Olsson and Chapman, 1996). Automatic machinery either detects when the predetermined weight of product has been fed into the bag, or uses an automatic shut-off when the bag (and contents) reaches a predetermined weight. The weight accuracy is generally around 0.25 to one per cent. Filling equipment for open-mouthed bags generally operates either by gravity feed, auger feed or conveyor-belt feed. Bags with valve-type closures are filled using centrifugal belt feeding, impeller feeding, auger feeding or fluidized bed feeding.

Once filled, bags can be closed using a range of methods including sewing, taping, wire tying, heat-sealing or ultrasonic sealing (Olsson and Chapman, 1996). Heat-sealing and the much less common ultrasonic sealing are used when absolute tightness is needed. Heat sealing requires a heat-sealable coating or inner ply on the bag. The closing of valve-type sacks is effectively automated owing to the construction of the valve.

The available emission factors for emissions during bagging are summarised in Table 0.3.

Table 0.3 Emission factors for losses during bagging

Chemical type	Emission factor	Emission media	Comment	Reference
Fertilizers and pesticides	0.095 kg TSP/tonne	Air		WHO, 1993
Lime	0.12 kg TSP/tonne	Air	Factor for lime packaging/shipping (the actual packaging was not stated)	WHO, 1993
Cement	2.2 kg/tonne clinker	Air	Factor for packaging (the actual packaging was not stated) – uncontrolled emission	WHO, 1993
	0.01 kg/tonne clinker	Air	Factor for packaging (the actual packaging was not stated – controlled emission (fabric filters)	WHO, 1993

3.2.8 Storage tanks

Available emission factors for the filling of storage tanks are summarised in Table 0.4. Similar to the situation with road tankers, the emission depends on the method used to fill the tank (such as splash filling, submerged filling or vapour balanced filling).

Most emissions from the filling of storage tanks will be volatile losses to the atmosphere.

Emissions of liquids can potentially occur during the filling of storage tanks from overfill and leakage. However, a large number of tanks will have some sort of secondary containment system that will collect such emissions for disposal. Secondary containment measures fall into two main types, those that are part of the tank construction (such as double tank bottoms, double skin and double wall tanks) and impervious barriers that are placed on the ground below the tank (European Commission, 2004). Leakage detection equipment may also be present in some types of tanks.

Double bottoms and impervious barriers are designed to protect against small but persistent leaks. Other barrier systems such as bunds are designed to contain large spills (such as those caused by rupture of the tank or a large overfill). A bund consists of an impervious wall around that outside of the tank. The size of the bund is such that it can accommodate the entire contents of the tank.

Table 0.4 Emission factors for losses during filling of storage tanks[a,b]

	Emission factor	Chemical type	Emission media	Comment	Reference
Underground tanks	1.5 kg VOC/m^3 2.03 kg VOC/tonne	Gasoline	Air	Splash filling	WHO, 1993
	1.0 kg VOCm^3 1.353 kg VOC/tonne	Gasoline	Air	Submerged filling	WHO, 1993
	0.16 kg VOC/m^3 0.217 kg VOC/tonne	Gasoline	Air	Balanced vapour filling	WHO, 1993
Fixed roof tank	0.36 kg VOC/tonne (range 0.00012-0.71 kg VOC/tonne	Reclaimed solvent	Air	Submerged or bottom loading	USEPA AP-42 Chapter 4.7
Underground storage tanks	0.34 kg NMVOC/tonne	Gasoline – unleaded	Air	Delivery at petrol stations.	NAEI, 2000
	0.34 kg NMVOC/tonne	Gasoline - leaded	Air	Delivery at petrol stations.	NAEI, 2000
Car fuel tanks	2.61 kg NMVOC/tonne	Gasoline – unleaded	Factor for vehicle refuelling.		NAEI, 2000
	2.62 kg NMVOC/tonne	Gasoline - leaded	Factor for vehicle refuelling.		NAEI, 2000

Note: a) The process of filling storage tanks is closely aligned with the emptying of the delivering tanker. It is assumed that the emission factors given here for volatile substances also include the contribution from emptying of the delivery tank or tanker. Where vapour recovery is employed, emissions at the storage tank site will be reduced.

b) No specific factors of this type were found for floating roof tanks. These are included in the TANKS model as discussed in Section 0.

In principal, emissions to waste water and soil from the filling of (and storage in) tanks should be minimal where appropriate secondary containment measures are in place.

3.2.9 Silos

The available emission factors for emissions during the filling of silos are summarised in Table 0.5.

The main source of emission is dust, and dust filters are normally installed in silos to reduce emissions during filling (European Commission, 2004). Dust filters commonly used on silos filter the displaced air as the silo is filled, and can achieve emission levels of 1-10 mg/m^3.

There is a danger of dust explosion when handling fine powders of organic material, and so special measures (such as purging with nitrogen) may need to be taken in the bulk handling and storage of such material (European Commission, 2004).

The supplier of bulk solid material will often take measures to minimise the potential for dust generation during filling of the silo (European Commission, 2004). Such measures can include screening or classifying the bulk material (a common cut size for fines to be separated is 100 µm), coating the bulk solids with a thin, adhesive layer, and minimising the amount of particles <10 µm.

Table 0.5 Emission factors for losses during transfer to silos

Chemical type	Emission factor	Emission media	Comment	Reference
Fluorspar	70 kg TSP/tonne	Air	The factor covers drying, transfer and storage – uncontrolled emission	WHO, 1993
	1.3 kg TSP/tonne	Air	The factor covers drying, transfer and storage – controlled emission (fabric filters, covers etc.)	

3.3 Emptying

3.3.1 Road tankers

Several methods of emptying road tankers can be used. In simple terms, they can be emptied either from the top or from the bottom, with different degrees of containment (such as vapour recovery systems).

Vapour balancing can be used for both the loading and unloading of road tankers (European Commission, 2004). During unloading of the tanker, vapours displaced from the receiving storage tank are collected through pipework and carried back to the road tanker from which the product is being transferred. Vapour balancing is only possible when unloading into non-pressurised fixed roof storage tanks.

In the UK, a number of different types of fittings are used between the storage tank and the road tank. The fittings may be carried on the tanker and have to be taken off once the load has been delivered. The fitting and transfer line may contain the chemical being transferred and so will present a source of emissions to the environment when it is removed from the tanker. There are a number of possible ways this can be dealt with. For example, the chemical in the fitting can be discharged (by gravity, pressure or pump, for example) into the storage tank or back into the transportation tanker. Alternatively, it may be sealed within the fitting and taken back with the tanker for cleaning or, in some situations, it may be spilled onto the floor. The issue that needs to be considered is whether unloading of the tanker is dedicated or not.

The situation within the rest of Europe is somewhat different to that in the UK in that a much smaller range of fittings are generally needed in the rest of Europe. In addition, standard fittings are used throughout the petroleum industry in the UK and Europe and so the fittings do not need to be removed from the tanker. Tankers for petrol have vapour recovery systems whereas tankers for diesel may not always have them (as diesel has a lower vapour pressure, such systems are not required). Where tankers deliver both petrol and diesel, recovery systems are present.

Many viscous or (semi-)solid products may be heated to facilitate emptying of the tanker.

The major source of losses associated with emptying of tankers results from the subsequent filling of the receiving storage tank (see Section 0), rather than from the emptying of the tanker itself. However, the emptied tanker will contain a residual amount of the chemical. For non-volatile chemicals, this residue will either remain in the tank and become part of the next load if the tanker is refilled with the same chemical (dedicated service), or be removed from the tanker when the tanker is cleaned (see Section 0).

Volatile chemicals will be lost to the air if the tanker is vented. This venting could take place when the tanker is being refilled or when the tanker is being cleaned.

No published emission factors have been found for the emptying of tankers alone, however, the process is closely aligned with the filling of storage tanks and so it is assumed that the emission factors given in Section 0 (for volatile substances) also include the contribution from emptying of the tanker.

3.3.2 Rail tankers

Losses from the emptying of rail tankers are in principle similar to those from road tankers. No published emission factors have been located in the literature.

3.3.3 Ship tankers

No published emission factors have been found relating specifically to the unloading of ship tankers. The process and sources of emissions are likely to be very similar to those from the unloading of other types of tankers. In principle, the use of vapour balancing techniques is possible when unloading ships and barges. However, only a limited number of general purpose seagoing tankers appear to be fitted with the necessary vapour collection pipework (European Commission, 2004).

3.3.4 Trucks

WHO (1993) gives an emission factor to air of 0.17 kg (TSP) per tonne for truck unloading (batch drop) for stone quarrying activities. No other information has been located for the emptying of trucks. Again, the unloading of bulk materials from trucks has the potential to generate dust emissions. The unloading of packaged chemicals is expected to result in minimal emissions to the environment.

3.3.5 Drums

No published emission factors have been found relating to the emptying of drums. The process has the potential to generate volatile emissions or particulate/dust emissions depending on the substance involved.

The Environment Agency (2004b) provides guidance on minimising emissions to the environment during the handling and storage of drums. Containment methods include bunds, kerbs, drip trays or any other systems that will prevent a spilled product escaping.

Small containers (25 kg or less) are emptied by hand. Conventional 205 litre drums are emptied either by gravity or by using a pump, but not by air pressure as this may cause the drum to burst. To avoid contamination, the drum is put on a collector pan (metal grating over a metal drip pan or other collection system). To dispense certain liquids (such as chlorinated solvents) a portable tank on wheels or a skid is sometimes used, and a drip retaining basin is applied. The unit has its own permanently mounted pump used exclusively for solvent transfer and a pressure relief valve.

Fibre drums are designed with a smooth cylindrical body with a flush interior surface, and can be emptied with a pressure plate. To encourage maximum use of these drums a selection of high release liners is available, and some drums (used for both solids and liquids) have a removable bottom cover that allows the users to recover virtually 100 per cent of the product.

3.3.6 IBCs

No published emission factors have been found relating to the emptying of IBCs. The process has the potential to generate volatile emissions or particulate/dust emissions, depending on the substance involved.

The Environment Agency (2004b) provides guidance on minimising the emissions to the environment during the handling and storage of IBCs. Containment methods include bunds, kerbs, drip trays or any other systems that will prevent a spilled product escaping.

Practices commonly employed to remove materials from IBCs include pouring, pumping and aspirating. IBCs have a bottom drain valve to allow complete tank drainage. Automatic discharge systems are available for a range of IBCs. Once an IBC has been placed onto the discharge system, the discharge equipment can be configured and controlled to suit the particular material or process. Contained continuous discharge, contained pulsed discharge or complete discharge can be achieved via the discharge valve. Weighing equipment can be integrated into the design to provide for gravimetric operation, and the system may be connected to filtered vents or extraction systems appropriate to the material or transfer.

3.3.7 Bags

The emptying of bags may generate dust emissions. Emissions from this process have been considered in previous ESDs. For example, the ESD for plastics additives (OECD, 2004) assumes three sources of emissions. Firstly, loss from wear and tear from the handling of bags and sacks is estimated at 0.1 per cent, and this loss is independent of particle size.

Secondly, the flow of solid from the bag can be affected by the presence of attractive forces between the individual particles. Such forces may have several origins, for example, mechanical interlocking, interfacial and capillary forces between adsorbed layers and for the finest particles, van der Waals forces. These attractive forces become significant for particles associated with adsorbed water when diameters are less than around 50 microns (μm) and for dry particles which are about two orders of magnitude smaller.

Adsorbed mono-layers of water are present on many particles and agglomeration effects are particularly apparent for particles of sizes < 40 μm. Such particles do not empty cleanly from the bag, and remaining particles may present a significant route of release to the environment. A worst case figure of as much as one per cent loss can be assumed for such situations. For particles > 40 μm, retention in the bag does not occur to a significant extent, and a minimal 0.01 per cent loss can be assumed. The material remaining in the packaging may be lost to the environment via solid waste into landfill.

Thirdly, dust may be generated during the emptying process. A worst case scenario for dust generation during bag emptying would be a loss of around 0.5 per cent for particle sizes less than 40 μm and 0.1 per cent for particle sizes greater than 40 μm.

Although the major source of emission is likely to be dust released into the air from the emptying of bags, particulates would be expected to settle rapidly within the workplace and so could lead to emissions to other phases, such as waste water or solid disposal, as a result of cleaning down of surfaces and so on.

3.3.8 Storage tanks

No specific emission factors have been found for losses during the emptying of storage tanks. Potential losses could occur to air (vapour losses) and water/soil (spills).

The ESD on plastics additives (OECD, 2004) assumes a nominal loss figure of 0.01 per cent from the bulk handling of liquid plasticizers in enclosed storage systems.

3.3.9 Silos

The main source of emission is dust emission (European Commission, 2004). Commonly, silos are emptied by a rotary feeder into a pneumatic conveying line or directly into a screw feeder. Any dust generated at the discharge point can be collected on filters. No specific emission factors have been found relating to the emptying of silos.

3.4 Storage of liquids

Available data on emissions during bulk storage of liquids in storage tanks is summarised in
Table 0.6. The main source of emissions is from breathing losses. Breathing losses occur as a result of displacement of overlying vapours from the expansion and contraction of the liquid, owing to changes in ambient temperatures and atmospheric pressure.

Several well-developed methods are available for estimating breathing losses from storage tanks. The methods used are too complex to reproduce here[13] but are published fully elsewhere (USEPA AP-42 amongst others), and are implemented in certain freely available software programs (such as the USEPA TANKS model[14]). It is recommended that these methods are used to estimate the emissions from liquids in storage tanks.

Table 0.6 Emission factors for losses during storage of liquids in tanks

Tank type	Chemical type	Emission factor	Emission media	Comment	Reference
Floating roof tank	Gasoline	1.14 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Crude oil	0.435 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Jet naphtha	0.415 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Jet kerosene	0.019 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Distillate oil	0.015 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
Fixed roof tanks	Gasoline	13.1 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Crude oil	2.8 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993

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[13] Some of the details are copyright of the publishing organisation.

[14] Available from: http://www.epa.gov/ttn/chief/software/tanks/index.html

Tank type	Chemical type	Emission factor	Emission media	Comment	Reference
	Jet naphtha	3.8 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Jet kerosene	0.19 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Distillate oil	0.17 kg VOC/m^3 storage capacity year	Air	Factor gives yearly emission. Not clear if this also includes filling losses.	WHO, 1993
	Reclaimed volatile organic solvent	0.01 kg VOC/tonne (range 0.002-0.04 kg VOC/tonne)	Air	Losses from storage tank vent.	USEPA AP-42, Chapter 4.7
Underground storage tanks	Gasoline – unleaded	0.25 kg NMVOC/tonne	Air	Factor for storage tanks at petrol stations.	NAEI, 2000
	Gasoline - leaded	0.25 kg NMVOC/tonne	Air	Factor for storage tanks at petrol stations.	NAEI, 2000
Not specified	Gasoline - unleaded	0.19 kg NMVOC/tonne	Air	Factor for storage at petrol terminals (most probably refers to floating roof tanks).	NAEI, 2000
	Gasoline - leaded	0.19 kg NMVOC/tonne	Air	Factor for storage at petrol terminals (most probably refers to floating roof tanks).	NAEI, 2000

For bulk storage of liquids, the main potential emission source from the transfer and handling system is from fugitive emissions (European Commission, 2004). Fugitive emissions generally result from vapours and liquids leaking from seals, connectors and flanges that should normally be tight. These emissions depend to a large extent on the pressure of the system but, with the exception of pressurised storage, the pressure within the transfer and handling system is relatively low compared with the pipework within the production or processing plant. Thus, fugitive emissions resulting from transfer and handling of liquids are usually significantly lower than those associated with the processing plant.

The European Commission (2004) gives some example figures for likely leakage rates from seals and pumps. The data was generated for pumps operating under normal conditions when handling mineral oils. The figures are summarised in Table 0.7.

Table 0.7 Example emission rates for pumps and seals in transfer lines (European Commission, 2004)

Seal type	Average emission to air during normal operation when handling mineral oils

Seal type	Average emission to air during normal operation when handling mineral oils
Improved single mechanical seal	1 g/h per seal (average) 0.42-1.67 g/h per seal (range)
Dual unpressurised seals with leakage collection	Close to zero (< 0.01 g/h per seal)
Dual pressurised seals	Close to zero (< 0.5 g/day per seal)
Seal-less pumps	No emissions (technically closed systems)

More detailed compilations of emission factors from pumps, seals and valves are also available, for example from the US Environmental Protection Agency (1995a). Consideration of such emission factors could allow estimates to be made for the specific circumstances at a site, but such factors are difficult to use in a generic sense.

Storage of liquids in other vessels such as drums, IBC and bottles is not expected to lead to significant losses to the environment unless there is an accident (such as a breakage).

3.5 Storage of solids

Published emission factors for losses during the storage of solids in open systems are summarised in
Table 0.8. Losses during the storage of solids in other storage and packaging systems are expected to be negligible.

The main source of emission from the storage of solids is from wind blown dust in open storage systems. Control measures that can be used to minimise these emissions include minimising exposure to the elements by use of sheds, roofs, domes, wind screens and covers or by moistening the stored product (if this is compatible with the product) (European Commission, 2004).

Table 0.8 Emission factors for losses during storage of solids

Chemical type	Emission factor	Emission media	Comment	Reference
Minerals (chemical and fertilizer)	20 kg TSP/tonne	Air	Open storage piles	WHO, 1993
Crushed materials (lime manufacture)	1 kg TSP/tonne lime	Air	Open storage piles	WHO, 1993
	0.5 kg TSP/tonne lime	Air	Semi-enclosed piles	WHO, 1993
	0.2 kg TSP/tonne lime	Air	Compartments	WHO, 1993
	0.2 kg TSP/tonne lime	Air	Silos	WHO, 1993
Cement	0.13 kg TSP/tonne clinker	Air	Silos	WHO, 1993

Chemical type	Emission factor	Emission media	Comment	Reference
Clinker (cement manufacture)	5.4 kg TSP/tonne clinker	Air	Open storage piles	WHO, 1993
	2.4 kg TSP/tonne lime	Air	Semi-enclosed piles	WHO, 1993
	0.12 kg TSP/tonne clinker	Air	Compartments	WHO, 1993
	0.12 kg TSP/tonne clinker	Air	Silos	WHO, 1993

Emissions from the bulk storage and transfer of toxic and/or reactive solids are generally negligibly small, as they are usually handled in closed systems or are stored in packaged form rather than loose material (European Commission, 2004).

3.6 Pipelines

Catastrophic failure of pipelines is not considered in this ESD. There are, however, a number of sources of systematic loss from pipelines that need to be considered. These include maintenance procedures and leakage through corrosion of valves and seals.

Losses from leakage of valves and seals are difficult to quantify as they depend to a large extent on the time period between the leak starting or being noticed and the faulty value or seal being replaced. For lagged pipes, such leaks could go unnoticed for a substantial period of time.

Figures on the incidences of leaks from oil pipes in Europe are published annually by the oil companies' European association for environment, health and safety in refining and distribution (CONCAWE). The latest figures available are for 2003 (CONCAWE, 2005). The gross spillage rate amounted to 3.5 parts per million (equivalent to 0.00035 per cent) of the total volume of oil-related products transported. Of this, nearly 90 per cent was from a single event (from which a large proportion of the spill was recycled or safely disposed of). The figures include losses resulting from mechanical failure or corrosion, and also third party activity (for example, leakages caused by groundworks affecting the pipelines). Hence the vast majority of the losses are not related to the normal operating conditions of the pipeline. As such, available information on releases does not allow reliable estimates to be made of losses under normal conditions.

3.7 Washing and cleaning

The following sections include information on the amount of material remaining in different containers before cleaning. The values for the fraction remaining are termed F_{resid} in Section 0.

3.7.1 Road tankers

Dedicated tankers are generally not cleaned, whereas non-dedicated tankers are cleaned. There are thought to be around 40 cleaning locations within the UK, some of which are in-house facilities at chemical manufacturing sites (NRTCA, personal communication). Of these 40 sites, around 35 are thought to clean ‘commercially’ and five clean only their own tankers. Of the 35 commercial sites, 21 are members of the NRTCA.

The number of tankers cleaned annually is estimated at 250,000 in the UK (with 177,000 of these being carried out by NRTCA members). The average number of tankers cleaned at an NRTCA members’ site is thus around 40 per day.

The amount of residual product remaining in the tanker when delivered to the cleaning station depends to a large extent on the viscosity of the product. High viscosity products tend to leave a viscous coating on the tanker wall, whereas for volatile solvents the inside of the tanker is generally dry when delivered to the cleaning station (although even in this case the tanker is still likely to be cleaned to satisfy the customer).

The first step of the tanker cleaning process is a visual inspection to look for residues. The amount of residue that is acceptable to the tanker cleaners depends on the chemical. Responsible tanker cleaners carry lists of chemicals for which visible residues are allowed (typically, chemicals that are not flammable or toxic). If the residue is above a level acceptable for cleaning (termed excess residue), it will either be drawn from the tanker for suitable disposal or, if it can’t be dealt with in this way, the tanker will be sent away (where it may go back to re-deliver, or go back to the manufacturing site).

When the residue is below a minimum level, the tanker is considered acceptable for cleaning. It is estimated that around 98 per cent of tankers arriving at cleaning stations are acceptable for cleaning. The general range of product left in a tanker that is acceptable for cleaning is between 0 and 250 litres in a 25,000 litre tanker (up to one per cent of the volume). The typical amount is 50 litres (0.2 per cent of the volume) and this corresponds to the amount that is just visible on inspection of the tank.

The wash process depends to some extent on the substance, but will generally consist of pressure washing with a standard acid- or alkali-based detergent followed by a clean water rinse. The cleaning solution is generally a mixture of water (98 per cent) and cleaning agents (2 per cent). The cleaning processes would generally use around 1-3 m^3 (typically 2 m^3) of water[15] and this water is disposed of following cleaning and not re-used. The method of disposal of waste water depends on the chemical being cleaned and the discharge consent for the site. This can be discharged to sewer (following appropriate on-site treatment) if the site consent allows it, or may be treated by an off-site licensed waste company.

For discharge to sewer, on-site treatment can vary from oil and grease interceptors to dissolved air flotation cells to, in some cases, on-site biological treatment (although biological treatment is more common in the rest of Europe than in the UK).

A small group of products, such as latex and some resins, are cleaned using a recycling system, whereby the cleaning solution is re-used and then disposed of after 10-20 cleaning cycles.

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[15] Range of volumes for cleaning in US estimated as 0.13 – 4.3 m^3 per tanker (USEPA, 2003)

The more responsible tanker cleaners in the UK and Europe have signed up to a European-wide standard of operation. The scheme[16] is operated by the European Chemical Industry Council (CEFIC) and consists of an operational audit, which includes details of what happens to the waste from the cleaning process. There is an ongoing effort to get more tanker cleaning companies to sign up to this initiative, and all members of the NRTCA operate within this scheme. However, some facilities within the UK and Europe are not currently operating within these constraints.

As well as potential losses to water, the cleaning process can also result in losses to air. USEPA AP-42 (Chapter 4.8) gives emission factors for emissions to air for road tanker car cleaning and these are summarised in Table 0.9 below. The actual emission factor depends on both the viscosity (as this relates to the residual amount of the chemical remaining in the tanker or in other words, the ease of draining of the tanker) and the vapour pressure. These are emissions per tanker. A different approach based on the tanker volume and the fraction of substance remaining is used later in Section 0.

As well as liquids, tankers can be used for the transport of solids such as powders, granules and pellets - these are also known as silo tankers. There is usually little residue remaining in the tanker for free-flowing products (such as plastic pellets) but some products such as titanium dioxide can stick to the tanker interior and form a thin film which needs to be removed by cleaning. In these cases, the amount of material adhering to the tanker interior can be up to 25 kg, equivalent to around 0.1 per cent of the total cargo for a 25,000 kg tanker load (NRTCA, personal communication).

Most cleaning stations are able to clean a wide variety of products. There is however, a growing trend for transporters to develop lists of compatible products in order to minimise the need to clean tankers (cost driven), and some chemicals manufacturers are starting to issue cleaning stations with lists of products that are not considered to be compatible with their product, even after cleaning, and so will not accept a tank which has carried one of these incompatible products as the previous load.

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[16] Further details of the scheme can be obtained from http://www.sqas.org/cleaning/index.html)

Table 0.9 Emission factors for losses to air during road tanker cleaning (USEPA AP-42, Chapter 4.8)

Chemical type		Example chemical[a]	Emission factor (g/tanker)
Volatility	Viscosity		
High	Low	Acetone [Vapour pressure 30 kPa Viscosity 0.41 centistokes]	311
High	Low	Perchloroethylene [Vapour pressure 3.3 kPa Viscosity 0.95 centistokes]	215
Medium	Medium	Methyl methacrylate [Vapour pressure = 4 kPa at 20°C Viscosity 0.52 cP at 25°C][b]	32.4
Low	Low	Phenol [Vapour pressure 0.5 kPa Viscosity 11.3 centistokes]	5.5
Low	High	Propylene glycol [Vapour pressure 0.011 kPa Viscosity 54 centistokes][c]	1.07

Note: a) Vapour pressure and kinematic viscosity data at 20°C were taken from http://www.engineersedge.com/fluid_flow/fluid_data.htm unless otherwise indicated.
b) Vapour pressure data taken from WHO (1998) and dynamic viscosity data taken from Riddle (1954).
c) Vapour pressure data at 20°C taken from IPCS (2000).

3.7.2 Rail tankers

Rail tankers are generally dedicated to a given chemical and so are not generally cleaned. There are few rail tanker cleaning facilities in Europe.

Information on emissions from the cleaning of rail tankers is available for the United States (USEPA AP-42, Chapter 4.8). A typical rail tanker cleaning facility cleans between four and 10 cars per day. The capacity of the rail tanker cars varies between 40 and 130 m^3. The tanker cars are cleaned using steam hoses, pressure wands or rotating spray heads through the opening in the top of the car. Scraping is sometimes necessary for hardened or crystallized products. Cleaning agents include water, steam, detergents, acids, alkalis and solvents. The amount of residual material cleaned from each car is estimated to be around 250 kg. Assuming that the rail tankers hold between 40 and 130 tonnes of chemical, this is equivalent to around 0.19-0.63 per cent of the volume. This figure is very close to that estimated above for the cleaning of road tankers. The volume of water used to clean rail tankers in the US is estimated as 0.3-9 m^3 per tanker (USEPA, 2003).

As well as potential losses to water, the cleaning process can also result in losses to air. USEPA AP-42 (Chapter 4.8) reports emission factors for releases to air for rail tanker car cleaning and these are summarised in Table 0.10. The actual emission factor depends on both the viscosity (as this relates to the residual amount of the chemical remaining in the tanker or in other words, the ease of draining of the tanker) and the vapour pressure.

Table 0.10 Emission factors for losses to air during rail tanker car cleaning (USEPA AP-42, Chapter 4.8)

Chemical type		Example chemical	Emission factor (g/car)
Volatility	Viscosity		
Low	High	Ethylene glycol [Vapour pressure 0.5 kPa Viscosity 18 centistokes]	0.3
Low	Medium	o-Dichlorobenzene	75.4
Medium	Medium	Chlorobenzene	15.7
Low	High	Creosote	2,350

Note a) Vapour pressure and kinematic viscosity data at 20°C were taken from http://www.engineersedge.com/fluid_flow/fluid_data.htm unless otherwise indicated.

3.7.3 Ship tankers

No information has been located on the emissions from cleaning ship tankers. As a first approach, it could be assumed that the residual level of substance in the tanker is around 0.19-0.63 per cent as estimated in Section 0. This amount of material could then be expected to be emitted to water during the cleaning operation. In addition to tank cleaning, ballast water may also be added to empty tanks and emptying of the ballast water (deballasting) could be a further potential source of emission.

As well as losses to water, the cleaning process could also potentially lead to emissions to air.

Regulations exist on the carriage of chemicals by ship (IMO, 2003). These currently categorize chemicals carried in bulk into one of four categories (Category A to D), each with their own requirements with regards to anti-pollution measures. However, new versions of these categories are expected to enter into force in January 2007[17] (as a revised Annex II to the regulations) and these are outlined below:

- Category X. Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, are deemed to present a major hazard to either marine resources or human health and, therefore, justify the prohibition of the discharge into the marine environment.

- Category Y. Noxious liquid substances which, if discharged into the sea from tank cleaning or deballasting operations, are deemed to present a hazard to either marine resources or human health

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[17] See http://www.imo.org/Environment/mainframe.asp?topic_id=236.

or cause harm to amenities or other legitimate uses of the sea and therefore justify a limitation of the quality and quantity of the discharge into the marine environment.

- Category Z. Noxious liquid substances which, if discharged into sea from tank cleaning or deballasting operations, are deemed to present a minor hazard to either marine resources or human health and therefore justify less stringent restrictions on the quality and quantity of the discharge into the marine environment.

- Other substances. Substances which have been evaluated and found to fall outside category X, Y or Z because they are considered to present no harm to marine resources, human health, amenities or other legitimate uses of the sea when discharged into the sea from tank cleaning or deballasting operations. The discharge of bilge or ballast water or other residues containing these substances are not subject to any requirements under these regulations.

The revised Annex II will also contain significantly lower permitted discharge levels of certain products, resulting from improvements in ship technology. For ships constructed on or after 1 January 2007, the maximum permitted residue in the tank and its associated piping left after discharge will be set at a maximum of 75 litres for products in categories X, Y and Z, compared with the current maximum limits of 100 or 300 litres depending on the product category.

A further International Convention exists with regards to the control and management of ship ballast water (IMO, 2004a). The original conventions should be consulted for details of the requirements related to specific chemicals.

3.7.4 Drums

Steel drums have a high level of re-use and a dedicated, world-wide reconditioning industry exists. Drum makers usually provide for the collection of used containers and the supply of reconditioned containers. Therefore, multi-trip usage of steel drums is commonplace.

Information on the IPA website[18] indicates that there are several companies within the United Kingdom offering recycling or reconditioning services for drums and other container systems. The number of IPA member companies carrying out such processes is listed below.

Steel drums[19]	8 companies
Plastic drums	8 companies
Fibre drums	6 companies
IBCs	13 companies
Hazardous waste containers	7 companies

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[18] http://www.theipa.co.uk.

[19] Note: In most cases, the same companies carry out recycling/reconditioning of all three types of drum.

The IPA recyclers/reconditioners offer a range of services including nationwide collection networks, dedicated reconditioning for customer re-use of their own packaging, supply of reconditioned packaging to certified standards and waste disposal and recycling services for non-reusable packaging.

Information on emissions to the environment from drum cleaning in the United States is available (USEPA AP-42, Chapter 4.8). Here, it is estimated that drums made from 18-gauge steel have an average life with total cleaning of around eight trips, and those with 20-gauge steel bodies and 18-gauge steel heads have an average life of around three trips. Not all drums, especially those of thinner construction, are cleaned.

Cleaning of drums in the United States is usually carried out by steam cleaning or washing with an aqueous alkaline cleaning. However, drums that contain substances that are difficult to clean may be burned out, either in a furnace or in the open.

Steam cleaning is carried out by inserting the cleaning nozzle into the drum and so volatile chemicals of low water solubility can be released to the atmosphere during the process. Alkaline cleaning is usually carried out by tumbling the sealed drum containing hot caustic solution and pieces of chain. As the drum is sealed during this process emissions to air are minimal.

Furnaces can operate either as a batch or continuous process. In the furnace, the drum is heated to between around 480°C and 540°C for around four minutes with gas burners. This burns away the contents of the drum (and the exterior paintwork of the drum). It was estimated that the average amount of material removed from each drum during such cleaning was 2 kg (USEPA AP-42 Chapter 4.8)`. Assuming the typical size of a drum is around 205 litres (or approximately 200 kg), this amounts to around one per cent of the drum contents.

Further information on the emissions from drum cleaning is available in USEPA (2002). According to this report, most open-head steel drums are recycled or cleaned by burning, whereas plastic or tight-head steel drums (such as bung-type) are recycled or cleaned by washing.

Water is used both for drum burning and drum cleaning. In drum burning, the main use of water is during the quenching stage. Most of this quenching water is lost by evaporation. Rinsing of the drums with water may also occur prior to painting but, by this stage the original contents of the drum will have been removed.

For drum cleaning, water can be used as an interior pre-flush, for the washing and rinsing process and for washing the exteriors of the drums, although the largest amounts are thought to be associated with the drum washing and rinsing.

According to USEPA (2002), most drum cleaning facilities discharge water to sewer, although it is possible that some sites may achieve effectively zero discharge of waste water by collecting such water for appropriate treatment off-site or recycling the waste water.

Various end-of-pipe treatment technologies may be used at drum cleaning facilities. These include equalization, pH adjustment, gravity settling, oil/water separation, chemical precipitation followed by clarification or air flotation, and sludge dewatering, although such treatment is not always present on-site (USEPA, 2002).

An example procedure at a drum washing facility is outlined below (based on USEPA, 2002, and Touhill et al., 1983).

1. Drum inspection. Damaged drums, drums that are not considered to be empty or drums that contain unacceptable materials are returned to the shipper.

2. Pre-cleaning (optional). This can entail pre-steaming or pre-flushing with water. The objective is to ease the removal of residual material from the drum during the subsequent washing.

3. Washing. This is usually carried out by spraying the interior of the drum with hot caustic solution. This can be done in an automatic drum cleaning machine (where the drums are placed upside down on a conveyor) or manually. For difficult to remove substances, the drums can be cleaned using chaining, whereby chains are placed in the drum along with the caustic cleaning solution and the drum is tumbled to remove the residue (this is not applicable to plastic drum washing). Alternatively, the drum may undergo two washing cycles. Caustic solution (such as sodium hydroxide and water) is the main cleaning solution used for steel drums, but detergent solutions can also be used in the case of plastic drums.

4. Rinsing. Following the wash, the drums undergo one or more rinses. For steel drums, the final rinse may contain a corrosion inhibitor additive such as sodium nitrite.

5. Drying. Plastic drums can be dried using vacuum siphons or hot air. Steel drums can be dried using vacuum siphons, hot air or flame treating.

6. Final inspection. The drums are inspected for rust[20] (steel drums) and to ensure they are clean. Steel drums can also be de-dented at this stage. The drums are also leak-tested (using pressurised air or submerged).

7. Cleaned steel drums that are to be repainted are shot-blasted, painted and then oven-cured.

8. The cleaned drums have bungs and fittings attached.

The actual processes (and order of processes) carried out at drum cleaning/recycling facilities can vary between facilities.

At some sites, cleaning solutions are used once and then disposed of whereas at other sites, cleaning solutions can be re-used until they are no longer effective. Thus, the same solution can be used over periods of weeks to a few months or longer. Make-up solution is periodically added to replace the solution lost during the cleaning process (final rinse) or to retain the efficiency of the solution. Water from the cleaning solution is also lost by evaporation during the cleaning process, and make-up water is commonly supplied by recirculated rinse water. If the cleaning solution is used for extended periods (longer than three months), then the cleaning solutions are also periodically treated to remove contaminants such as solids and oil.

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[20] Rusty drums are cleaned using a hydrochloric acid solution using the same process outlined for washing with caustic solution.

The spent cleaning solution may be sent off-site for appropriate disposal, or, if compatible with the waste water treatment system, it may be discharged to waste water. At some sites, cleaning solutions can be effectively used indefinitely (with appropriate make-up) and are essentially never discharged or disposed of.

If a steel drum cannot be cleaned satisfactorily, it is either crushed for recycling of the steel, or is converted into an open-head drum and sent for burning. Plastic drums that cannot be cleaned can be shredded and sold on to a plastics recycler. USEPA (2002) estimates that the percentage of drums for cleaning that are scrapped or recycled in this manner is around 14 per cent for steel tight-head drums, 20 per cent for plastic tight-head drums and 24 per cent for plastic open-head drums.

An example procedure at a drum burning facility is outlined below (based on USEPA, 2002; HMIP, 1992; Defra, 2004d; and Touhill *et al.*, 1983). This process is only carried out with open-head steel drums.

1. Drum inspection. Damaged drums or drums that are not considered to be empty are returned to the shipper. The contents of the drums are further drained by up-ending the drum and allowing the excess liquid to drain into the waste collection container. In the UK, this waste should be disposed of as controlled waste to a licensed waste management facility.

2. Burning. This is often carried out in tunnel-type continuous furnaces. The drums are placed upside down on a moving chain in the furnace, and the drum lids also pass through the furnace along with the drum. The furnace operates at a temperature of around 600°C. An afterburner (thermal oxidiser) operating at around 1,000°C can be used to control emissions to air from the process. In the UK, a temperature of at least 850°C for at least two seconds in the presence of at least six per cent by volume should be achieved at the inner wall of the combustion or afterburner chamber or, if halogenated waste is being burned, the temperature should be raised to at least 1,100°C (HMIP, 1992). A baghouse can also be used as an alternative to control emissions. The drums exiting the furnace are cooled by a steam curtain (this also removes any ash from the drums).

3. Quenching. On leaving the furnace, the drums are quenched with water. Air cooling can also be used in place of water.

4. Rinsing. The cooled drums are rinsed with water. The water may contain a corrosion inhibitor (one per cent sodium nitrite).

5. Shot-blasting. Residual paint is removed by shot-blasting (both inside and outside the drum).

6. De-denting and re-chiming. The drums are de-dented (by curling, expanding and body rolling) and the bottom chime is sealed on a chime roller.

7. Inspection and leak-testing. The drums are inspected for rust and to ensure they are clean. Leak-testing (by submersion) is also carried out.

8. Painting. The final stage is to dry, paint and oven-cure the drums, and to fit the drum lids and rings. Also at this stage, an interior coating can be applied to the drum.

For continuous furnaces, Touhill *et al.* (1983) report that the drums move through the furnace at an average rate of six to eight drums per minute. The average residence time for the drum in the furnace is 6.6 minutes.

USEPA (2002) estimates that the percentage of drums for cleaning that are scrapped/recycled (for steel) following burning is 6.1 per cent.

Information on the chemicals last contained in drums at cleaning facilities is given in USEPA (2002). This is summarised in Table 0.11.

Table 0.11 Chemical types last contained in drums at cleaning facilities (USEPA, 2002)

Drum content	Percentage of drums for cleaning
Oil and petroleum products	36.2%
Industrial chemicals	15.6%
Paints and inks	14.8%
Cleaning solvents	8.8%
Resins	8.8%
Adhesives	6.8%
Food	6.8%
Other	1.7%

USEPA (2002) estimates that the amount of waste water generated during drum cleaning is around 4-9 gallons (15-34 litres) per drum washed for steel drums and 9-10 gallons (34 to 38 litres) per drum washed for plastic drums. These figures consider water from all sources (such as washing, rinsing, formulation of the cleaning solutions and external washing of the drum). Waste water recycling systems can reduce the volume of water used. An approximate mid-range figure of 30 litres will be assumed in this report to represent a reasonably typical case.

For drum burning, USEPA (2002) estimated a water consumption of around 10.6 gallons (40 litres) per drum burned. However, a significant proportion of the water consumed is lost through evaporation during the quenching phase, and a figure of 2.8 gallons per drum was thought to reflect the amount of waste water generated during the process.

The total waste water flow from drum reconditioning facilities (washing and burning) in the United States is reported to range from 500 to 50,000 gallons per day (1,893 to 189,250 litres per day), with an average flow of 14,300 gallons per day (54,100 litres per day) (USEPA, 2002). A similar figure of 15,000 gallons per day (56,800 l/day) was quoted by Touhill *et al.* (1983) for a typical drum washing facility.

The total number of drums reconditioned in the United States[21] in 2004 is estimated at around 15.2 million tight-head steel drums, 16.0 million open-head steel drums, 4.5 million tight-head plastic drums and 0.7 million open-head plastic drums. The average scrapping rate for drums was given as 13 per cent of those received.

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[21] See http://www.reusablepackaging.org/statisti.cfm.

USEPA has regulations in place (40 CFR 261.7) for drums that contain residues of hazardous materials. Under this rule, containers which retain any amount of hazardous material must be treated as hazardous waste unless the following standards are met by the emptier:

- all residues have been removed that can be removed using practices commonly employed to remove materials from that type of container (such as pouring, pumping, aspirating);
- no more than 2.5 cm of residue remains on the bottom or inner container;
- alternatively, no more than three percent by weight of the total capacity of the container remains in the container or inner lining if the container is less than or equal to 110 gallons (416 litres) in size.

If the above criteria are met, the drum is considered to be empty and can undergo cleaning/reconditioning. For certain highly hazardous wastes, the drum or liner should be triple rinsed with an appropriate organic solvent (or cleaned using another method of similar efficiency) before it can be considered to be empty.

According to OECD (2004b), current requirements by drum reconditioners in the UK for the lubricants industry are that for drums to be classified as 'empty', they must contain less than one per cent by weight of residue. Many lubricant additives are viscous in nature, and appreciable quantities can remain in the drums if no special precautions are taken. Since the cost of additives is generally very much higher than the cost of the base oil, lubricant blenders take care to ensure that the minimum quantities of additives remain in the drum.

In practice, once the contents of an additive drum have been removed, normally by inserting a standpipe, base oil is transferred back to the drum in order to dilute any residue and flush the drum before sucking the contents back. Thus, if the maximum of one per cent of the additive package is left in the drum initially, this will be diluted 100-fold with base oil on rinsing. When this oil is removed, the drum will then contain a maximum of one per cent of the diluted additive in oil, with a maximum additive package content of 0.01 per cent. The drums will then be sent to drum reconditioners for complete cleaning. On arrival at the reconditioning plant, drums are examined to assess the thickness, physical condition and previous contents before being categorised and designated for the type of reconditioning required. Drums are reconditioned by cleaning internally and externally with an aqueous caustic solution or by furnace cleaning and shot blasting. In the US, all drums containing petroleum-based materials are furnace cleaned in reconditioning.

Touhill *et al.* (1983) indicate that the average amount of residue in drums received by reconditioners in the United States was around 2.5 litres or 2.5 kg at that time. For a 205 litre drum, this is around 1.2 per cent by volume.

According to Touhill *et al.* (1983), many drum reconditioners in the United States specialize in the processing of oil drums only and nearly two-thirds of the facilities in the United States have oil-recovery systems. It was reported that for a typical plant processing 1,000 drums a day, around 22,700 litres of oil are recovered monthly.

Touhill *et al.* (1983) also report that drums containing certain types of chemical residues (especially pesticides but also some products such as inks and adhesives) may be refused at many facilities, as they need special handling and processing procedures.

The water treatment method used at the facility may generate sludges (Touhill *et al.*, 1983). These sludges will contain the less soluble, more adsorptive substances and would normally be disposed of as hazardous waste in an appropriate manner.

In addition to emissions to waste water, emissions to air could also occur during drum cleaning but not drum burning (here, it is assumed that the vapours will be burned during the process). This may be the main source of emissions for highly volatile substances.

3.7.5 IBCs

The market for re-use of IBCs is high, with a return rate of 98 per cent being typical. However, not all of these IBCs will be cleaned as a lot of the time they will be refilled with the same chemical without washing.

As indicated in Section 0, there are around 13 member companies of the IPA in the United Kingdom that offer recycling or reconditioning services for IBCs.

Overall, the situation with regards to washing and cleaning of IBCs is thought to be less well controlled than for road tankers. Although there are a number of reputable companies specialising in this area, the cleaning of IBCs can be done more easily than tankers and so the situation at some sites could be less well controlled than at a specialist, dedicated IBC cleaning site.

The emissions from IBC cleaning have been considered in USEPA (2002). The sources of emissions to waste water are thought to be similar to those from drum washing identified above. The following example procedure at an IBC washing facility was thought to be typical for all types of IBC.

1. Identification of cargo last carried in the container. The decision over whether the container can be cleaned and the subsequent method used is dependent on the cargo last carried in the container. At this stage, it is also determined if the residue in the container is compatible with the sites waste water treatment system and discharge consent, and if there are any health and safety issues for employees cleaning the container. The facility may decide to reject a container based on any of the above.

2. Container inspection. Once a container has been accepted for cleaning it is necessary to evaluate the volume of residue in the container and determine an appropriate strategy for management and/or disposal of the residue. Containers with excess residue are returned to the shipper. Water soluble residues that are compatible with the facility's treatment system and discharge consent are usually disposed of in the waste water stream from the site. Incompatible residues are collected in drums or tanks for disposal by authorised methods (such as incineration, landfilling or sold to a reclamation facility). Some residues (such as soaps, detergents, solvents, acids or

alkalis) may be re-used on site as cleaning solutions. Pre-flushing of the container with water may also be carried out.

3. Wash. Several cleaning methods (or combination of cleaning methods) can be used. The cleaning method depends on the cleaning equipment available at the facility and the cargo last held in the container. Some residual materials may only require a hot water wash for a few seconds, while other (more viscous, less soluble) residual materials may need to be washed using more aggressive cleaning agents such as detergent or strong caustic solutions, followed by a final water rinse. Hardened or caked-on products may require extended processing times (for several minutes or longer) with chemical cleaning solutions. Cleaning is normally carried out using spinner nozzles (which are inserted inside the container) or manually with hand-held wands and nozzles.

4. Clean fittings and valves. The valves and fittings are normally removed from the container and cleaned by hand. Gaskets may also be replaced at the same time.

5. Rinse container interior.

6. Wash the exterior of the container. Exterior washing is usually carried out with hand-held wands and can be done at the same time as the interior wash.

7. Dry the container. This can be carried out by ambient air or heated air.

8. Final inspection and leak test. Leak testing is usually carried out by partially filling the container with water to a level above the valve.

Information on the main cargos transported in IBCs in the United States is given in USEPA (2002). This is summarised in Table 0.12.

Table 0.12 Cargos transported in IBCs (USEPA, 2002)

IBC content	Percentage of IBCS
Oil and petroleum products	20%
Chemicals (including industrial chemicals, paints, resins, dyes)	70%
Food	10%

Similar to the case with drum cleaning described above, cleaning solutions are generally re-used (with appropriate make-up) until they are considered inefficient, and then disposed of either to waste water (provided they are compatible with the waste water treatment system) or sent off-site for appropriate disposal.

According to USEPA (2002) the amount of waste water generated during cleaning of IBCs is highly variable and depends on the type of IBC, the cargo transported and the final cleanliness required. Figures of 5 to 300 gallons (19 to 1,136 litres) per IBC cleaned are quoted, with the most typical figures being in the region of 45 to 100 gallons (170 to 379 litres) per IBC. These figures reflect the total water use (for interior cleaning, exterior cleaning, leak testing, rinsing, and so on). An approximate mid-range figure of 250 litres will be assumed in this report to represent a reasonably typical case.

The number of IBCs reconditioned annually in the United States is estimated at around 500,000 (USEPA, 2003), with just over half (275,000) being cleaned by drum reconditioners and the rest by transport equipment cleaners (tanker cleaners etc.).

USEPA has regulations in place (40 CFR 261.7) on IBCs that contain residues of hazardous materials. Under this rule, containers which retain any amount of hazardous material must be treated as hazardous waste unless the following standards are met by the emptier:

- all residues have been removed that can be removed using practices commonly employed to remove materials from that type of container (such as pouring, pumping, aspirating);
- no more than 2.5 cm of residue remains on the bottom or inner container;
- alternatively, no more than 0.3 percent by weight of the total capacity of the container remains in the container or inner lining if the container is greater than 110 gallons in size[22].

If the above criteria are met, the IBC is considered to be empty and can undergo cleaning/reconditioning. For certain highly hazardous wastes, the container or liner should be triple rinsed with an appropriate organic solvent (or cleaned using another method of similar efficiency) before it is considered to be empty. Based on the above discussion, for the construction of the emission scenario, it will be assumed that the maximum residue of hazardous materials in IBCs for cleaning will be around 0.3 per cent of the capacity. However, a higher residue figure of one per cent will also be considered for some substances in line with the information reported for residues for both road tankers (Section 0) and drums (Section 0). These values are used as F_{resid} in Section 0.

In addition to emissions to waste water, emissions to air could also occur during IBC cleaning and this may be the main source of emissions for highly volatile substances.

3.7.6 Storage tanks

Storage tanks may be cleaned at intervals, for example, when changing from one chemical to another. Cleaning is generally carried out on-site using specialist waste companies. The cleaning is usually carried out by jet washing and the cleaning company will take away the washings for suitable disposal. Such cleaning is a specialised operation (in some cases, the operatives may need to enter the tanks in order to clean them) and would need a permit from the appropriate authority for it to be undertaken.

As well as on-site storage tanks, fixed storage tanks can also be rented at some locations, and these would need to be cleaned out at the end of the renting period. Such storage companies are generally situated around ports. In addition, temporary storage tanks are available. These tanks are delivered by truck to the desired location and are then taken to a tanker cleaning station for cleaning after they have been used.

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[22] In practice, this has been interpreted to mean that for IBCs with capacities between 275 and 330 gallons, slightly less than one gallon of product may remain in an "empty" IBC (see http://www.reusablepackaging.org/emptyibc.cfm).

In addition to cleaning, some storage tanks may need to be drained at intervals to remove water and other substances, for example during the storage of crude oil. This process could potentially lead to emissions to the soil beneath the tank (European Commission, 2004). This draining can either be done manually, semi-automatically or automatically. Any water drained from the tank is usually collected in a drainage or sewer system for further treatment of the water. Draining is normally stopped when the water still contains < 10 per cent oil. Semi-automatic and automatic drains monitor the oil content of the drained water. In the case of a semi-automatic drain, this is by means of a float which floats in water but sinks in oil. Automatic drains use more sophisticated techniques such as measurement of refractive index or dielectric constant to distinguish between oil and water. These systems shut off the drain once an appropriate limit is reached.

Sludge can also be formed in tanks during the storage of some types of product (European Commission, 2004). The sludge formed is generally a mixture of the product, water and solids such as sand, scale and rust particles. The amount of sludge formed depends on a number of factors including product type, temperature, standing time, type of tank bottom, method of receipt (such as tanker or pipeline) and the capacity for mixing. Mixing of the tank contents by impeller mixers or jet mixers can help prevent deposition of sludge. In the past (and in some situations today), air was used for mixing; however, this has the potential to lead to emissions to air of volatile substances. When the depth of sludge within the tank reaches an unacceptable level (and cannot be reduced by mixing alone), the tank then needs to be cleaned.

3.8 Recycling

3.8.1 Drums

Plastic drums can be recycled in several ways as follows[9]:

- Incineration with heat recovery.
- Recycling. Plastic containers can be chipped, washed and turned into post-consumer recycle material (PCR). PCR material can be used as a raw material for the manufacture of non-food industrial and consumer plastic containers and for domestic and garden products (such as dustbins, composters, water butts). In the future, it may be possible to recycle plastic drums by techniques such as polymer cracking (which returns the plastic back into a hydrocarbon feedstock).
- Re-use and reconditioning. Many industries (including the catering, institutional chemical, photographic, water treatment and crop protection industries) are moving to a ‘closed-loop’ system whereby the plastic containers are re-used. Plastic drums are also suitable for cleaning in traditional reconditioning facilities (see Section 0).

At the end of their useful life, scrap steel drums are usually segregated and processed for recycling into new steel. The drums are often collected alongside other standard grades of scrap steel.

Similarly fibre drums can also be recycled at the end of their useable life. In this case, the fibre drum can be split out into its constituent elements and recycled.

Overall, the potential for emissions from the former contents of the drum during these recycling processes appears to be generally low.

3.8.2 IBCs

IBCs can, in principal be recycled in similar ways to drums. The methods used depend on the construction material used in the IBC (such as plastic or steel). Again, the potential for emissions from the former contents of the IBCs during recycling appears to be low.

3.8.3 Bags and other packaging

Bags and other packaging are generally disposed of rather than recycled, although recycling could be undertaken in some cases (for example, for paper sacks).

3.9 Disposal

The potential for emissions to the environment from disposal of used packaging depends on: a) the residual amounts of chemical in the packaging; and b) the method of disposal. The residual amounts of chemical in various types of packaging are summarised in the sections below.

For most packaging, the likely routes of disposal are landfill or incineration. Incineration is likely to completely destroy any residual chemical in the packaging, resulting in essentially no emissions to the environment. Substances present in packaging disposed of to landfill can potentially leach from the landfill or volatilise from the landfill. It should be noted, however, that such routes of emission are complex, and modern landfills are designed to minimise such emissions. Although such routes are possible, the actual quantification of emissions from landfills is beyond the scope of this ESD.

Within the United Kingdom, non-domestic packaging waste is considered as hazardous or special waste if it is possible to obtain a sample of a hazardous substance from the packaging amounting to 0.1 per cent (either by weight or volume) of the nominal maximum capacity of the packaging (Environment Agency, 2004c). For certain hazardous substances (for example, substances classified as very toxic or carcinogenic Category 1 or 2), a lower limit of 0.01 per cent applies. In this respect, the method of obtaining the sample relates to practices commonly employed to remove material from the type of packing concerned, such as pouring, pumping, rinsing, aspirating, shaking, scraping or chipping. In addition, packaging that is contaminated by waste liquid with a flash point < 21°C is also considered as special waste.

3.9.1 Drums

As discussed in Section 0, the maximum residual amount of chemical remaining in drums that are considered to be empty is around one per cent for more viscous, non-volatile products. If the drum is rinsed before disposal, this figure will fall to around 0.01 per cent (assuming a dilution of 100 occurs during rinsing). Assuming a drum contains around 205 litres, this is around a maximum of two litres of chemical being disposed of to landfill per drum discarded.

3.9.2 IBCs

As discussed in Section 0, the maximum residual amount of chemical remaining in IBCs that are considered to be empty is around 0.3 per cent. Assuming a typical IBC contains around 1,000 kg of chemical, this corresponds to a maximum of around 3 kg of chemical being disposed of to landfill per IBC disposed.

3.9.3 Bags

As discussed in Section 0, the maximum residue of solids remaining in bags after emptying is around one per cent for particles < 40 µm and 0.01 per cent loss for particles > 40 µm. Assuming a typical bag contains around 25 kg of solid, this corresponds to a maximum of around 0.25 kg (particle size < 40 µm) or 0.0025 kg (particle size > 40 µm) of chemical being disposed of to landfill per bag disposed.

3.9.4 Consumer packaging and other end-use packaging

Consumer products (for use by either the general public or professionals) containing chemicals (usually as a formulated product such as a paint, cleaning agent, bleach, personal care product, sealant or adhesive) are supplied in a large range of containers including tins, tubes, bottles, spray cans manufactured out of metal, plastic and glass. Little information is available on the residues of chemicals and products that may be present in such packaging at disposal.

For certain types of products, for example washing up liquids, shampoos, liquid detergents and cleaners, it is very likely that the container will be rinsed out at the end (in order to try to use any remaining product) and so the packaging will not contain significant amounts of product or chemicals at disposal. Also, the increased availability of doorstep collection for recycling of such packaging also means that such packaging is likely to be rinsed out prior to disposal/recycling.

ECB (2002) gives some information on the packaging of sealants in general. Once formulated, the sealant is pumped directly from the mixing vessel to fill cartridges (for example, for one-part sealants) or tins (for example, for two-part sealants). Some sealants (such as one-part) are supplied in the form of cartridges typically containing around 500 g of sealant. In use, around 2-3 cm^3 of sealant is estimated to remain in the nozzle and tube when the cartridge has been emptied. This will quickly skin over and be protected inside the packaging. The final destination of these discarded cartridges will be as waste to landfill. Other sealants (such as two-part) are supplied in tins. Immediately before use, a curing agent is added to the tin and mixed with the sealant. The sealant is then filled into a cartridge on-site prior to application. Again, any unused material will quickly cure and set hard and will be disposed of in an appropriate manner. For industrial applications in the United Kingdom, the waste sealants are treated as special waste rather than general building waste. Based on the above discussion, the major loss of sealant during use (application) will be as solid waste.

The European Commission (2003c) provides an ESD for paints and coatings. This indicates that for decorative paints used by the general public, the total emissions to soil (such as landfill) resulting for the non-volatile components are up to 12 per cent. This emission consists of drips, discarded application instruments (such as brushes) and residues in the bottom of cans. The corresponding figure for professional painters is in the region of four to six per cent.

4. CHOICE OF TRANSPORT AND STORAGE SYSTEM

One of the key considerations for this ESD is the type or types of transport, packaging and storage systems that could be used for a given chemical. Once this is identified, the resulting emissions can be estimated using the methods outlined in Section 0. This section considers some of the factors that affect the choice of transport, packaging and storage systems and provides methods for determining the most likely transport, packaging and storage systems that will be used for a given chemical, if the actual system is unknown.

4.1 Factors affecting the choice of transport and storage system

The main factors affecting the choice of transport and storage method are:

- regulatory requirements;
- tonnage;
- phase at room temperature;
- hazardous properties;
- viscosity/solubility and other relevant physico-chemical properties such as vapour pressure;
- location of production sites in relation to processing;
- cost of transport/storage;
- value of chemical.

Some of these factors are dependent on each other. For example, a hazardous chemical will have certain regulatory requirements that govern transport and storage conditions.

4.2 Methods for determining transport and packaging type

In cases where the actual transport and packaging type used for chemical is not known, consideration of the regulatory requirements that may apply can be useful to identify the potential types of transport and packaging systems that can be used. Section 0 outlines the regulatory requirements with regards to transport of chemicals in the EU (similar requirements apply world-wide), and Section 0 outlines a generic method that can be used to determine the most likely transport and packaging type used to carry a given chemical. In all cases, if the actual transport and packaging type used for the chemical of interest is known, this should be used in the emission scenario document in preference to the generic approach outlined.

4.2.1 Regulatory requirement approach

Within the UK, the transport of dangerous substances by road and rail comes under the Carriage Regulations (HMSO, 2004). These regulations implement the European Agreement concerning the Carriage of Dangerous Goods by Road (known as the ADR) (European Commission, 2003a; UN, 2004a)) and the Regulations concerning the International Carriage of Dangerous Goods by Rail (known as the RID) (European Commission, 2003b), along with various EU Directives.

The ADR is published by the United Nations and is updated biannually. The latest version (ADR 2005) is applicable from January 2005 (UN, 2004a). The RID is also regularly updated and the latest (2005) version is published by the Intergovernmental Organisation for International Carriage by Rail (OTIF, 2005). Similar international agreements exists regarding the carriage of dangerous goods by inland waterways (known as ADN) (UN, 2004b) and sea (known as IMDG) (IMO, 2004b).

The various regulations all use a similar classification scheme for identifying classes of dangerous substances and the subsequent labelling, packaging and transportation requirements. A summary outline of the ADR is given in Appendix A. As discussed in Appendix A, the regulations consider nine main classes of dangerous substances. Substances within each class are generally assigned to one of three packing groups in accordance with the degree of danger they present, although different criteria/groupings are used for some classes such as explosives and gases. The three packing groups are as follows.

Packing group I: Substances presenting high danger.
Packing group II: Substance presenting medium danger.
Packing group III: Substance presenting low danger.

A whole host of criteria is used to assess which class and packing group (or other grouping) a given substance (or preparation containing one or more substances) is applicable. A summary of the main points are outlined in Table 0.1 below. However, the procedure is complex with many criteria (too many to be replicated here), and so it is recommended that the ADR 2005 is consulted for specific substances. Part 3 of the ADR 2005 also contains the dangerous goods list which outlines the appropriate class, packing group for many chemicals or groups of chemicals.

For any given substance, the hazardous properties of the substance (or articles or preparations containing the substance) may fall within one of more classes or groups. The ADR 2005 gives the following order of precedence for determining the overall classification of the substance for transport (UN, 2004a). The ADR 2005 should be consulted for full details of the procedure.

1. Substances or material of Class 7 (apart from radioactive material in excepted packages where other hazardous properties take precedence).

2. Substances of Class 1 (explosive substances and articles).

3. Substances of Class 2 (gases).

4. Liquid desensitised explosives of Class 3.

5. Self-reactive substances and solid desensitised explosives of Class 4.1.

6. Pyrophoric substances of Class 4.2.

7. Substances of Class 5.2 (organic peroxides).

8. Substances of Class 6.1 (toxic substances) or Class 3 (flammable liquids) which, on the basis of their inhalation toxicity, are to be classified under packing group I [Note: substances meeting the criteria of Class 8 and having an inhalation toxicity for dusts and mists (LC_{50}) in the range of packing group I but toxicity through oral ingestion or dermal contact only in the range of packing group III, should be allocated to Class 8]

9. Infections substances of Class 6.2

10. Other classes.

Once the packing group has been identified, ADR 2005 gives packing instructions for the various groups considered (UN, 2004a). The maximum amounts of dangerous substances (or preparations containing dangerous substances) that can be carried in the various types of packaging are summarised in Table 0.2 (liquids) and Table 0.3 **Allowed packaging and maximum amounts of dangerous solids that can be transported by road by packaging type (UN, 2004a)**

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
Single packaging	Drums – non-removable head – steel, aluminium, other metal, plastics	400 kg	400 kg	400 kg
	Drums – removable head – steel, aluminium, other metal, plastic	400 kga	400 kga	400 kg2
	Drums – fibre and plywood	400 kga	400 kga	400 kga
	Jerricans – non-removable head – steel, aluminium, plastic	120 kg	120 kg	120 kg
	Jerricans – removable head – steel, aluminium, plastic	120 kga	120 kga	120 kga
	Boxes – steel, aluminium, natural wood, plywood, reconstituted wood, natural wood with sift-proof walls, fibreboard and solid plastic	Not allowed	400 kga	400 kga
	Bags	Not allowed	50 kga	50 kga
Composite packaging	Plastics receptacle with outer steel, aluminium or plastics drum	400 kg	400 kg	400 kg

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
	Plastics receptacle with outer plywood or fibre drum	400 kga	400 kga	400 kga
	Plastics receptacle with outer steel or aluminium crate or box, or solid plastics box	75 kg	75 kg	75 kg
	Plastics receptacle with outer wooden, plywood or fibreboard box	75 kga	75 kga	75 kga
	Glass receptacle with outer steel, aluminium drum or with outer steel or aluminium crate or box, or with outer solid plastics packaging	75 kg	75 kg	75 kg
	Glass receptacle with outer plywood or fibre drum or with outer wooden or fibreboard box or with outer wickerwork hamper or expanded plastics packaging	75 kga	75 kga	75 kga
IBCs	Metal	3,000 litres	3,000 litres	3,000 litres
	Flexiblea, rigid plastic, compositea, fibreboarda and woodena	1,500 litres	3,000 litres	3,000 litres

Note: a) This type of packaging cannot be used for transporting substances that may become liquid during carriage. This is defined as those substances with a melting point ≤ 45°C.

4.2.2 Generic approach

A key part of developing an emission scenario is the identification of relevant packaging types and transport and storage systems that could be used for a given chemical of interest. From the discussion in Section 0 it can be seen that a wide range of packaging types could be used for any given chemical, and this needs to be reflected in the emission scenarios generated. However, it may not always be practical to consider every eventuality for a given chemical and so there needs to be some method for identifying the most relevant combinations of transport, packaging and storage systems that apply to a given situation.

(solids). Packing instructions also specify the exact type and materials that can be used for the packaging. The packing instructions are complex, and some restrictions and special provisions may apply for certain chemicals, groups of chemicals or combinations of hazardous properties (for example explosives or peroxides). It is not feasible to discuss all of the instructions and provisions in this document, and so reference to ADR 2005 is recommended in cases where the actual packaging type applicable to the substance under consideration is required (Part 3 of the

ADR 2005 outlines the appropriate packing instructions for many chemicals or groups of chemicals).

It should be noted that for most new and existing chemicals the actual UN class, packaging group, packaging numbers and packaging instructions should be known (or available from the materials safety data sheet), and so the permitted types of packaging that can be used can be identified specifically for the chemical of interest by consulting the ADR 2005 (UN, 2004a) or the equivalent document for transport by rail (OTIF, 2005) inland waterways (UN, 2004b) or sea (IMO, 2004b).

For the bulk storage of solids, a further consideration in the choice of storage system is the susceptibility of the material to be dispersed (for example, by wind), and the possibility for reducing this susceptibility by wetting. The following classification system can be used (European Commission, 2004):

- S1 – Highly drift sensitive, not-wettable.
- S2 – Highly drift sensitive, wettable.
- S3 – Moderately drift sensitive, not wettable
- S4 – Moderately drift sensitive, wettable
- S5 – Not or very slightly drift sensitive.

Table 0.1 Summary of criteria used for assessing the packing group for dangerous substances transported by road (UN, 2004a)

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
1. Explosive substances		See UN (2004a)	See UN (2004a)	
2. Gases	Compressed gas Liquefied gas Refrigerated liquefied gas Dissolved gas Aerosol dispensers and receptacles Other articles containing gas under pressure Non-pressurised gases subject to special requirements.	Asphyxiant (A)	Gases which are non-oxidising, non-flammable and non-toxic which dilute or replace oxygen normally in the atmosphere.	Within the regulations, a gas is defined as a substance with a vapour pressure > 300 kPa at 50°C or a substance that is completely gaseous at 20°C at the standard pressure of 101.3 kPa.
		Oxidising (O)	Gases which may (by providing oxygen) cause or contribute to the combustion of other material more than does air.	
		Flammable (F)	Ignitable when in a mixture of 13% or less by volume with air or have a flammable range in air of at least 12 percentage points regardless of the lower flammability limit.	
		Toxic (T)	Substances which are known to be so toxic or corrosive to humans as to pose a health hazard or substance that have a LC_{50} value ≤ 5,000 ppm.	
		Toxic, flammable (TF)	See above.	
		Toxic, corrosive (TC)	See above.	
		Toxic, oxidising (TO)	See above.	
		Toxic, flammable, corrosive (TFC)	See above.	
		Toxic, oxidising, corrosive (TOC)	See above.	
3. Flammable liquids	Flammable liquids, without subsidiary risk (F)	Packing group I	Boiling point ≤ 35°C.	Within the regulations, this covers liquids that have a

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
	Flammable liquids, toxic (FT) Flammable liquids, corrosive (FC) Flammable liquids, toxic, corrosive (FTC) Liquid desensitised explosives (D)	Packing group II	Flash point (closed cup) < 23°C and boiling point > 35°C. Different criteria apply to viscous liquids.	vapour pressure of < 300 kPa at 50°C and that are not completely gaseous at 20°C and a standard pressure of 101.3 kPa and a flash point ≤ 61°C.
		Packing group III	Flash point (closed cup) ≥ 23°C ≤ 61°C and boiling point > 35°C. Different criteria apply to viscous liquids.	
4.1 Flammable solids, self-reactive substances and solid desensitised explosives	Flammable solids, without subsidiary risk (F) Flammable solids, oxidising (FO) Flammable solids, toxic (FT) Flammable solids, corrosive (FC)	Packing group II	Readily flammable solids which, when tested, have a burning time of 45 seconds over a measured distance of 100 mm and the flame passes the wetted zone. This also applies to metal powders or powders of metal alloys if, when tested, they can be ignited by a flame and the reaction spreads over the whole length of the sample in five minutes or less.	This class covers readily flammable solid substances and preparations, self-reactive solids or liquids, solid desensitised explosives and substances related to self-reactive substances.
		Packing group III	Readily flammable solids which, when tested, have a burning time of 45 seconds over a measured distance of 100 mm but the flame is stopped by the wetted zone for at least four minutes. This also applies to metal powders or powders of metal alloys if, when tested, they can be ignited by a flame and the reaction spreads over the whole length of the sample more than five minutes.	
	Solid desensitised explosives without subsidiary risk (D) Solid desensitised explosives, toxic (DT)	Solid desensitised explosives	Solid desensitised explosives are substances which are wetted with water or alcohols or are diluted with other substances to suppress their explosive properties.	

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
	Self-reacting substances (SR)	Self-reacting substances	Thermally unstable substances liable to undergo a strongly exothermic decomposition even without the participation of oxygen or air. The substances have a heat of decomposition of ≥ 300 J/g and a self-accelerating decomposition temperature of ≤ 75°C for a 50 kg package.	This definition does not include explosives (covered in Class 1), oxidising substances (covered in Class 5.1 or organic peroxides (covered in Class 5.2)
4.2 Substances liable to spontaneous combustion	Substances liable to spontaneous combustion, without subsidiary risk (S) Substances liable to spontaneous combustion, which, in contact with water, emit flammable gases (SW) Substances liable to spontaneous combustion, oxidising (SO) Substances liable to spontaneous combustion, toxic (ST) Substances liable to spontaneous combustion, corrosive (SC)	Packing group I	Substances liable to spontaneous combustion (pyrophoric). For solids, this is defined as substances that ignite on falling from a height of 1 m or within 5 minutes. For liquids, this is defined as a substance which, on being poured onto an inert carrier, ignites within 5 minutes or when poured onto a dry, indented filter paper, ignites or carbonizes the paper within 5 minutes.	Covers pyrophoric substances and self-heating substances.
		Packing group II	Self-heating substances. These are defined as substances and articles in which spontaneous combustion, or a rise in temperature to over 200°C, is observed within 24 hours on heating a 2.5 cm sample cube at 140°C.	
		Packing group III	Slightly self-heating substances. These are defined as substances and articles in which spontaneous combustion, or a rise in temperature to over 200°C, is observed within 24 hours on heating a 10 cm sample cube at 140°C.	

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
4.3 Substances which, in contact with water, emit flammable gases	Substance which, in contact with water, emit flammable gases, without subsidiary risk, and articles containing such substances (W) Substances which, in contact with water, emit flammable gases, liquid, flammable (WF1) Substances which, in contact with water, emit flammable gases, solid, flammable (WF2) Substance which, in contact with water, emit flammable gases, solid, self-heating (WS) Substances which, in contact with water, emit flammable gases, oxidising,	Packing group I	Substances that react vigorously with water at ambient temperature and generally demonstrate a tendency for the gas produced to ignite spontaneously, or substances that react readily with water at ambient temperatures such that the rate of evolution of flammable gas is equal to or greater than 10 litres per kg of substance over any one minute period.	
		Packing group II	Substances that react readily with water at ambient temperature such that the maximum rate of evolution of flammable gas is equal to or greater than 20 litres per kg of substance per hour, and which do not meet the criteria for packing group I.	

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
	solid (WO) Substances which, in contact with water, emit flammable gases, toxic (WT) Substances which, in contact with water, emit flammable gases, corrosive (WC) Substances which, in contact with water, emit flammable gases, flammable, corrosive (WFC)	Packing group III	Substances that react slowly with water at ambient temperature such that the maximum rate of evolution of flammable gas is greater that 1 litre per kg of substance per hour, and that does not meet the criteria for packing groups I or II.	
5.1 Oxidising substances	Oxidising substances without subsidiary risk or articles containing such substances (O) Oxidising substance, solid, flammable (OF) Oxidising substances, solid, self-heating (OS)	Packing group I	Solid substances that exhibit a mean burning time less than the mean burning time of a 3:2 mixture (by mass) of potassium bromate and cellulose in the standard test. Liquid substances that spontaneously ignite in the standard test or where the mean pressure rise time in the standard test is less than that of a 1:1 mixture (by mass) of 50% perchloric acid and cellulose.	The standard test for solids is the 4:1 or 1:1 sample-to-cellulose ratio (by mass) test. The standard test for liquids is the 1:1 mixture (by mass) sample-to-cellulose test.

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
	Oxidising substances, solid which, in contact with water, emit flammable gases (OW) Oxidising substances, toxic (OT) Oxidising substances, corrosive (OC) Oxidising substance, toxic, corrosive (OTC)	Packing group II	Solid substances that exhibit a mean burning time equal to or less than the mean burning time of a 2:3 mixture (by mass) of potassium bromate and cellulose in the standard test, and the criteria for packing group I are not met. Liquid substances that show a mean pressure rise time in the standard test of less than or equal to that of a 1:1 mixture (by mass) of 40% sodium chlorate solution and cellulose, and the criteria for packing group I are not met.	
		Packing group III	Solid substances that exhibit a mean burning time equal to or less than the mean burning time of a 3:7 mixture (by mass) of potassium bromate and cellulose in the standard test, and the criteria for packing groups I and II are not met. Liquid substances that show a mean pressure rise time in the standard test of less than or equal to that of a 1:1 mixture (by mass) of 65% nitric acid and cellulose, and the criteria for packing groups I and II are not met.	
5.2 Organic peroxides	Organic peroxides, not requiring temperature control (P1) Organic peroxides, requiring temperature control (P2)	Organic peroxides, not requiring temperature control	Any organic peroxide unless the organic peroxide formulation contains not more than 1.0% available oxygen from the organic peroxides when containing not more than 1.0% hydrogen peroxide, or not more than 0.5% available oxygen from the organic peroxides when containing more than 1.0% but not more than 7.0% hydrogen peroxide.	
		Organic peroxides, not requiring temperature control	As above but where the self-accelerating decomposition temperature is ≤ 45°C to ≤ 50°C (refer to UN, 2004a for specific details).	

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
6.1 Toxic substances	Toxic substances without subsidiary risk (T) Toxic substances, flammable (TF) Toxic substances, self-heating, solid (TS) Toxic substances, which, in contact with water, emit flammable gases (TW) Toxic substances, oxidising (TO) Toxic substances, corrosive (TC) Toxic substances, flammable, corrosive (TFC)	Packing group I	Highly toxic substances. Acute oral $LD_{50} \leq 5$ mg/kg or acute dermal $LD_{50} \leq 40$ mg/kg or acute inhalation toxicity (for dusts and mists) ≤ 0.5 mg/l. For vapours, the volatility of the substance is also taken into account in terms of the saturated vapour concentration (V) in air at 20°C (in units of ml/m^3). Highly toxic substances are those where V ≥ 10 times the acute inhalation LC_{50}, and the LC_{50} is ≤ 1,000 ml/m^3.	In this method, the acute inhalation LC_{50} relates to 1-hour exposures. Where data relating to 4-hour exposure are available, the LC_{50} value should be multiplied by 2.
		Packing group II	Toxic substances. Acute oral LD_{50} > 5-50 mg/kg or acute dermal LD_{50} > 40-200 mg/kg or acute inhalation toxicity (for dusts and mists) > 0.5-2 mg/l. For vapours, the volatility of the substance is also taken into account in terms of the saturated vapour concentration (V) in air at 20°C (in units of ml/m^3). Toxic substances are those where V ≥ the acute inhalation LC_{50}, and LC_{50} is ≤ 3,000 ml/m^3.	
		Packing group III	Slightly toxic substances. Acute oral LD_{50} > 50-200 mg/kg (solids) or acute oral LD_{50} > 50-500 (liquids) or acute dermal LD_{50} > 200-1,000 mg/kg or acute inhalation toxicity (for dusts and mists) > 2-10 mg/l. For vapours, the volatility of the substance is also taken into account in terms of the saturated vapour concentration (V) in air at 20°C (in units of ml/m^3). Slightly toxic substances are those where V ≥ 0.2 times the acute inhalation LC_{50}, and the LC_{50} is ≤ 5,000 ml/m^3.	

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
6.2 Infectious substances	Infectious substance affecting humans (I1) Infectious substances affecting animals only (I2) Clinical waste (I3) Diagnostic specimens (I4)	Category A	An infectious substance which is carried in a form that, when exposure to it occurs, is capable of causing permanent disability, life-threatening of fatal disease to humans or animals.	
		Category B	An infectious substance which does not meet the criteria for inclusion in Category A.	
7 Radioactive material		See UN (2004a)	See UN (2004a)	
8 Corrosive substances	Corrosive substances, without subsidiary risk (C) Corrosive substances, flammable (CF) Corrosive substances, self-heating (CS) Corrosive substances which, in contact with water, emit flammable gases (CW) Corrosive substances, oxidising (CO) Corrosive substances, toxic	Packing group I	Highly corrosive substances. Substances that cause full thickness destruction of intact skin tissue within an observation period of up to 60 minutes starting after the exposure time of 3 minutes or less.	
		Packing group II	Corrosive substances. Substances that cause full thickness destruction of intact skin tissue within an observation period of up to 14 days starting after the exposure time of more than 3 minutes by not more than 60 minutes.	

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
	(CT) Corrosive substances, flammable, liquid, toxic (CFT) Corrosive substances, oxidising, toxic (COT)	Packing group III	Slightly corrosive substances. Substances that cause full thickness destruction of intact skin tissue within an observation period of up to 14 days starting after the exposure time of more than 60 minutes but not more than 4 hours or substances that are judged to not cause full thickness destruction of intact skin tissue but which exhibit a corrosion rate on steel or aluminium surfaces exceeding 6.25 mm a year at a test temperature of 55°C.	
9 Miscellaneous dangerous substances and articles	Substances which, on inhalation as fine dust, may endanger health (M1)	Packing group II	Substances presenting medium danger – no precise criteria are given	Examples include asbestos and mixtures containing asbestos
		Packing group III	Substances presenting low danger – no precise criteria are given	
	Substances and apparatus which, in the event of fire, may form dioxins (M2)	Packing group II	Substances presenting medium danger – no precise criteria are given	Examples include polychlorinated biphenyls and terphenyls, polyhalogenated biphenyls and terphenyls, mixtures containing these substances as well as apparatus such as transformers that may contain these substances or mixtures of these substances.
		Packing group III	Substances presenting low danger – no precise criteria are given	
	Substances evolving flammable vapour (M3)	Packing group II	Substances presenting medium danger – no precise criteria are given	Examples include polymers containing flammable liquids with a flash point of ≤ 55°C.
		Packing group III	Substances presenting low danger – no precise criteria are given	
	Lithium batteries (M4)	Packing group II	Substances presenting medium danger – no precise criteria are given	See UN (2004a) for special provisions.
		Packing group III	Substances presenting low danger – no precise criteria are given	

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
	Life-saving appliances (M5)	Packing group II	Substances presenting medium danger – no precise criteria are given	See UN (2004a) for special provisions.
		Packing group III	Substances presenting low danger – no precise criteria are given	
	Environmentally hazardous substances: Pollutant to the aquatic environment, liquid (M6) Environmentally hazardous substances: Pollutant to the aquatic environment, solid (M7)	Packing group II	Substances presenting medium danger – no precise criteria are given	Substances classified as N: R50; R50/53 or R51/53.
		Packing group III	Substances presenting low danger – no precise criteria are given	
	Environmentally hazardous substances: Genetically modified micro-organisms and organisms (M8)	Packing group II	Substances presenting medium danger – no precise criteria are given	
		Packing group III	Substances presenting low danger – no precise criteria are given	
	Elevated temperature substances, liquid (M9) Elevated temperature substances, solid (M10)	Packing group II	Substances presenting medium danger – no precise criteria are given	Examples include substances that are carried or handled in the liquid state at or above 100°C and, in the case of substances with a flash-point, below their flash-point. This also includes solids that are carried or handled at temperatures at or above 240°C.
		Packing group III	Substances presenting low danger – no precise criteria are given	
	Other substances presenting a danger during carriage,	Packing group II	Substances presenting medium danger – no precise criteria are given	Examples include solid ammonia compounds with a

Class	Sub-divisions[a]	Grouping	Criteria use	Comment
	but not meeting the definitions of another class (M11)	Packing group III	Substances presenting low danger – no precise criteria are given	flash-point below 61°C, low hazard dithionites, highly volatile liquids, substances emitting toxic fumes, substances containing allergens and chemical kits and first aid kits.

Note: a) The subdivisions relate to the possible combinations of hazardous properties that affect the choice of packaging. For a given combination the criteria for both classes would apply. For example, for the sub-division 'Oxidising substance, toxic' both the criteria for oxidising substances (Class 5.1) and toxic substances (Class 6.1) would need to be considered. A hierarchy for the overall classification or grouping is given in UN (2004a) and is summarised in the text below.

Table 0.2 Allowed packaging and maximum amounts of dangerous liquids that can be transported by road by packaging type (UN, 2004a)

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
Single packaging	Drums – non-removable head – steel, aluminium, other metal, plastic	250 litres	450 litres	450 litres
	Drums – removable head – steel, aluminium, other metal, plastic	250 litres[a]	450 litres	450 litres
	Jerricans – non-removable head – steel, aluminium, plastic	60 litres	60 litres	60 litres
	Jerricans – removable head – steel, aluminium, plastic	60 litres[a]	60 litres	60 litres
Composite packaging	Plastics receptacle with outer steel or aluminium drum	250 litres	250 litres	250 litres
	Plastics receptacle with outer fibre, plastics or plywood drum	120 litres	250 litres	250 litres
	Plastics receptacle with outer steel or aluminium crate or box, or outer wooden, plywood, fibreboard or solid plastics box	60 litres	60 litres	60 litres
	Glass receptacle with outer steel, aluminium, fibreboard, plywood, solid plastics or expanded plastic drum, or with outer steel or aluminium crate or box, outer wooden or fibreboard box or with outer wickerwork hamper	60 litres	60 litres	60 litres
IBCs[b]	Rigid plastic or metal	Not allowed	3,000 litres	3,000 litres

Note: a) Only substances with a viscosity of > 2,680 mm^2/s can be transported in this packaging.
b) IBCs (metal, rigid plastics or composite) generally can only be used for the transport of liquids with a vapour pressure ≤ 110 kPa at 50°C or 130 kPa at 55°C (UN, 2004a).

Table 0.3 Allowed packaging and maximum amounts of dangerous solids that can be transported by road by packaging type (UN, 2004a)

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
Single packaging	Drums – non-removable head – steel, aluminium, other metal, plastics	400 kg	400 kg	400 kg
	Drums – removable head – steel, aluminium, other metal, plastic	400 kg[a]	400 kg[a]	400 kg[2]
	Drums – fibre and plywood	400 kg[a]	400 kg[a]	400 kg[a]
	Jerricans – non-removable head – steel, aluminium, plastic	120 kg	120 kg	120 kg
	Jerricans – removable head – steel, aluminium, plastic	120 kg[a]	120 kg[a]	120 kg[a]
	Boxes – steel, aluminium, natural wood, plywood, reconstituted wood, natural wood with sift-proof walls, fibreboard and solid plastic	Not allowed	400 kg[a]	400 kg[a]
	Bags	Not allowed	50 kg[a]	50 kg[a]
Composite packaging	Plastics receptacle with outer steel, aluminium or plastics drum	400 kg	400 kg	400 kg
	Plastics receptacle with outer plywood or fibre drum	400 kg[a]	400 kg[a]	400 kg[a]
	Plastics receptacle with outer steel or aluminium crate or box, or solid plastics box	75 kg	75 kg	75 kg
	Plastics receptacle with outer wooden, plywood or fibreboard box	75 kg[a]	75 kg[a]	75 kg[a]
	Glass receptacle with outer steel, aluminium drum or with outer steel or aluminium crate or box, or with outer solid plastics packaging	75 kg	75 kg	75 kg
	Glass receptacle with outer plywood or fibre drum or with outer wooden or fibreboard box or with outer wickerwork hamper or expanded plastics packaging	75 kg[a]	75 kg[a]	75 kg[a]
IBCs	Metal	3,000 litres	3,000 litres	3,000 litres

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
	Flexible[a], rigid plastic, composite[a], fibreboard[a] and wooden[a]	1,500 litres	3,000 litres	3,000 litres

Note: a) This type of packaging cannot be used for transporting substances that may become liquid during carriage. This is defined as those substances with a melting point ≤ 45°C.

4.2.2 Generic approach

A key part of developing an emission scenario is the identification of relevant packaging types and transport and storage systems that could be used for a given chemical of interest. From the discussion in Section 0 it can be seen that a wide range of packaging types could be used for any given chemical, and this needs to be reflected in the emission scenarios generated. However, it may not always be practical to consider every eventuality for a given chemical and so there needs to be some method for identifying the most relevant combinations of transport, packaging and storage systems that apply to a given situation.

When considering a specific chemical, it is likely that relevant information on the actual transport, packaging and storage system used for the given application will be available from the supplier (or may even be reported on the material safety data sheet). However, in the absence of such information, the generic approach below could be used. It should be noted that, owing to the large number of possible combinations and circumstances, it is not possible to comprehensively identify all of the most relevant combinations for a given situation, but the approach below does provide a starting point in this respect.

The basic approach takes account of the tonnage produced or used at a site, along with the physico-chemical properties (whether the substance is supplied as a solid, liquid or gas), and the hazardous properties (the UN packing group).

- Step 1: Determine the amount of the substance used at the site of interest per day. This can either be based on actual known figures or estimated using the A- and B-Tables from the EU Technical Guidance Document (European Commission, 2003c). The amount used per day can then be used to decide if delivery of the substance is most likely to be in bulk, for example by road tanker, or in smaller packaging such as drums, bags, or IBCs, using the flow chart in Figure 4.1.

- Step 2: Identification of main delivery type. The flow chart in Figure 4.1 outlines an approach that could be taken.

- Step 3: Identification of the packaging group for the given substance. This can be obtained from the supplier of the substance or can be determined from the information reported in Section 0. The exact types of packaging system that can be used for the chemical (and the maximum amount of chemical that can be transported by that system) can then be determined from Table 0.2 (for dangerous liquids) or Table 0.3 **Allowed packaging and maximum amounts of dangerous solids that can be transported by road by packaging type (UN, 2004a)**

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
Single packaging	Drums – non-removable head – steel, aluminium, other metal, plastics	400 kg	400 kg	400 kg
	Drums – removable head – steel, aluminium, other metal, plastic	400 kga	400 kga	400 kg2
	Drums – fibre and plywood	400 kga	400 kga	400 kga
	Jerricans – non-removable head – steel, aluminium, plastic	120 kg	120 kg	120 kg
	Jerricans – removable head – steel, aluminium, plastic	120 kga	120 kga	120 kga
	Boxes – steel, aluminium, natural wood, plywood, reconstituted wood, natural wood with sift-proof walls, fibreboard and solid plastic	Not allowed	400 kga	400 kga
	Bags	Not allowed	50 kga	50 kga
Composite packaging	Plastics receptacle with outer steel, aluminium or plastics drum	400 kg	400 kg	400 kg
	Plastics receptacle with outer plywood or fibre drum	400 kga	400 kga	400 kga
	Plastics receptacle with outer steel or aluminium crate or box, or solid plastics box	75 kg	75 kg	75 kg
	Plastics receptacle with outer wooden, plywood or fibreboard box	75 kga	75 kga	75 kga
	Glass receptacle with outer steel, aluminium drum or with outer steel or aluminium crate or box, or with outer solid plastics packaging	75 kg	75 kg	75 kg
	Glass receptacle with outer plywood or fibre drum or with outer wooden or fibreboard box or with outer wickerwork hamper or expanded plastics packaging	75 kga	75 kga	75 kga
IBCs	Metal	3,000 litres	3,000 litres	3,000 litres
	Flexiblea, rigid plastic, compositea, fibreboarda and woodena	1,500 litres	3,000 litres	3,000 litres

Note: a) This type of packaging cannot be used for transporting substances that may become liquid during carriage. This is defined as those substances with a melting point ≤ 45°C.

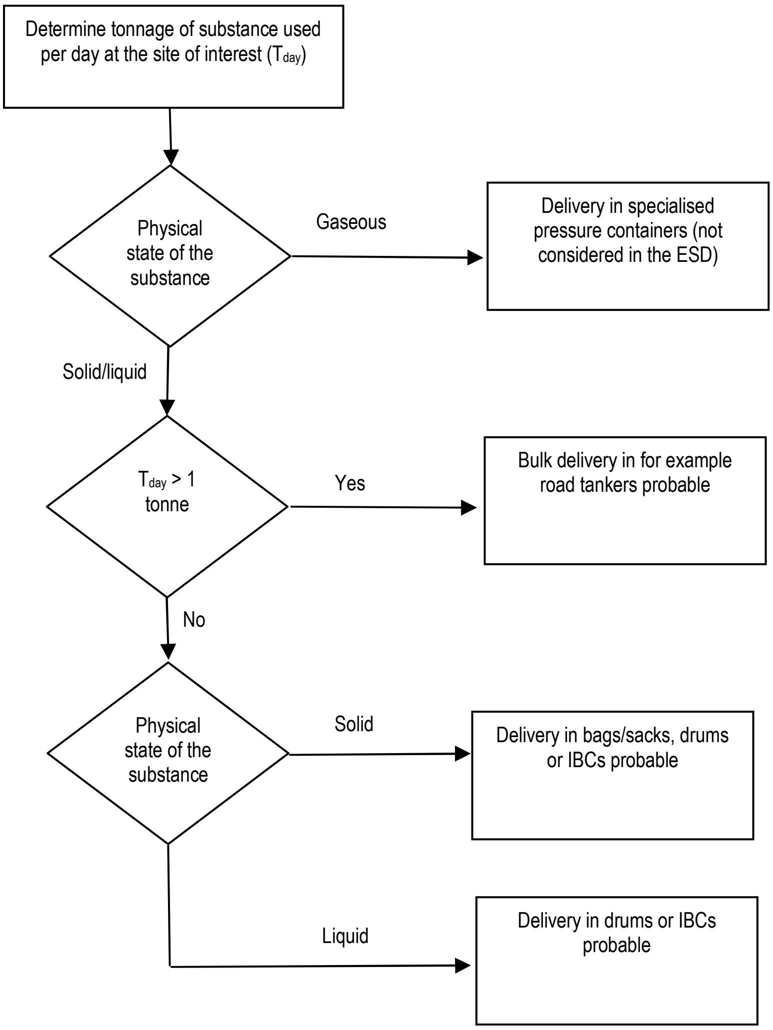
4.2.2 Generic approach

A key part of developing an emission scenario is the identification of relevant packaging types and transport and storage systems that could be used for a given chemical of interest. From the discussion in Section 0 it can be seen that a wide range of packaging types could be used for any given chemical, and this needs to be reflected in the emission scenarios generated. However, it may not always be practical to consider every eventuality for a given chemical and so there needs to be some method for identifying the <u>most relevant</u> combinations of transport, packaging and storage systems that apply to a given situation.

- (for dangerous solids). For substances not considered to be dangerous under transport legislation, it should be assumed that any of the suitable packaging types could be used.

As indicated above, this approach is necessarily simplistic and generalised. There are other factors that may need to be taken into account in the decision-making process. For example, high value chemicals or high purity chemicals are more likely to be transported in smaller packaging (such as bags or drums) than in bulk tankers in order to maintain the quality of the product. In addition, some highly toxic chemicals such as pesticides are also more likely to be transported in smaller packaging, to reduce the possibility of worker exposure during transit.

Figure 4.1 Flow chart for identification of main delivery type



The one tonne per day cut-off is essentially an arbitrary figure. It is probable that bulk tanker deliveries are made at sites using less than this, and that deliveries in bags and drums are made to sites using higher amounts than this.

For on-site storage, it should be assumed that deliveries in smaller packages are stored within these containers prior to use. Bulk deliveries, however, will be stored in on-site storage tanks (liquids) or silos[23] (solids). The amounts stored will depend on the number of deliveries made and the rate of use of the substance. This type of information is site specific and cannot be easily estimated in a generic fashion.

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[23] Some types of solids (for example relatively low value, non-toxic solids, minerals or ores) may be stored in piles.

5. EMISSION SCENARIOS

5.1 Introduction

In the absence of more specific information, the following steps can be followed to generate emission estimates during transport and storage of chemicals.

1. Identify the relevant transport, packaging and storage systems (Section 0).
2. Identify the relevant lifecycle stages and operations (see Figure 5.1 and discussion below).
3. Determine the size of local operation for each lifecycle stage and operations (Section 0).
4. Estimate local emissions from each lifecycle stage (Sections 0 to 0).
5. Estimate aggregated emissions on a regional or country-wide basis if required (Section 0).

This section outlines methods that can be used to develop emission scenarios for the transport and storage of chemicals using the above approach. Two main aspects need to be considered when estimating emissions from a particular operation or combination of operations relating to the transport and storage of chemicals. The first relates to the size of the tanker, storage tank or container being filled/emptied/stored/cleaned/recycled at a given site. This is known as the size of operation. The second aspect is the quantitative emission from the operation (for example, the percentage emission from filling a drum). A combination of these two pieces of information then allows emissions to be estimated for a wide range of possible situations.

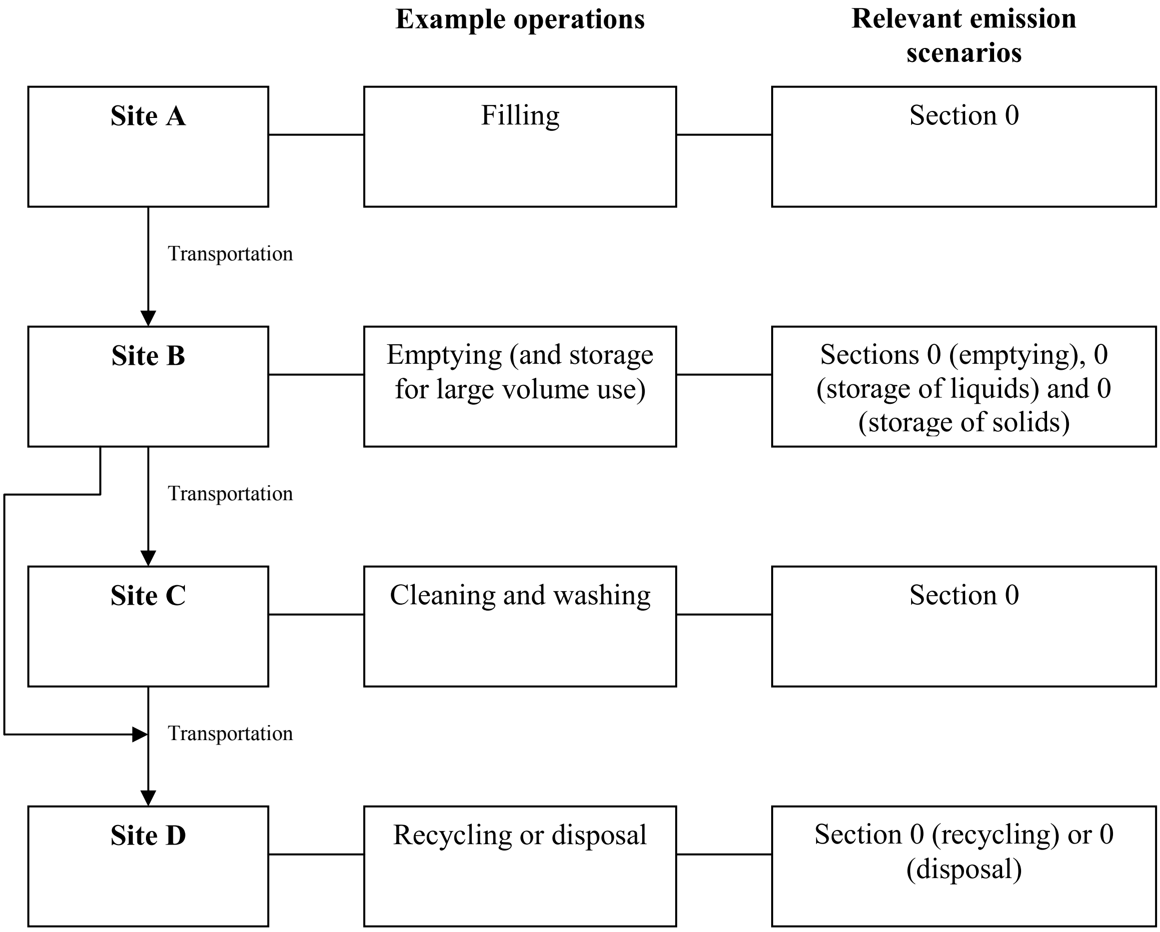
The method used to estimate the emissions from the lifecycle stage or operation depends on the data available for the specific substance in question. If specific emission factors are available for the substance, then the method outlined in Section 0 can be used to generate emission scenarios and estimates for the substance. However, this method is only applicable to the (limited) number of chemicals and processes for which actual emission factors are available.

In order to make this ESD applicable to as wide a range of substances as possible, a number of generic emission scenarios are also developed, based on relatively simple physico-chemical properties of the chemicals and assumptions of the main sources of release. The resulting emission estimates obtained with these generic scenarios are less reliable than those using a specific emission factor approach, and this should be born in mind when using the resulting emission estimates.

The generic emission scenarios are laid out by operation in Sections 0 (filling), 0 (emptying), 0 (storage of liquids), 0 (storage of solids), 0 (transfer in pipelines), 0 (washing and cleaning), 0 (recycling) and 0 (disposal). These consider emissions from the operation for each relevant type of transport and storage system at a local scale at a site where the operation takes place. This method of presenting the available data means that the document is flexible in that it allows the user to readily estimate emissions for all the lifecycle stages related to transport and storage.

It is difficult to be prescriptive about what actual lifecycle stages will be relevant for a given chemical. Figure 5.1 below gives a typical example of the stages that could occur during the transport and storage of a chemical, but many other combinations may also exist. In the absence of specific data for the chemical of interest, it is recommended that a lifecycle similar to that in Figure 5.1 is assumed in the first case. However, specific information on the relevant lifecycle steps should always be used in preference to Figure 5.1 if data is available.

Figure 5.1 Examples of possible operations carried out on local sites



When considering emissions at a local scale, it is important to remember that most of the operations will not occur on the same site. For example, drums will be filled on one site, transported to another site where they are emptied, and finally either cleaned, recycled or disposed of at a third site. Thus, when considering local emissions from any one site, only the operations relevant to that site should be taken into account. Methods for aggregating emissions from several sources over larger regional scales are outlined in Section 0.

The generic emission scenarios are generally derived for pure substances or for bulk mixtures/preparations. However, it is possible to apply a similar approach to individual components of mixtures and preparations. The assumptions and equations that need to be taken into account for specific components of mixtures and preparations are discussed below in general terms, and reference is made to these equations in the emission scenarios as relevant.

For solid and liquid phases

$$M_{comp} = M_{prep} \times f_{comp}$$ Equation 1

Explanation of symbols:			
M_{comp}	Quantity of the specific component present in the preparation or mixture	[kg]	
M_{prep}	Quantity of the preparation or mixture	[kg]	Substance-specific information
f_{comp}	Weight fraction of the specific component in the preparation or mixture	[-]	Substance-specific information

For vapours, the fraction that a given component makes up of the total vapour depends on the partial vapour pressures of all components in the vapour. This clearly is a very preparation-specific parameter. However, a simplified approach can be taken if the vapour is assumed to be essentially a two-component system consisting of the ‘preparation’ and the specific component of interest. In this case, the relevant equations for estimating the amount of specific chemical of interest in the total vapour are outlined below. This approach relies on the availability of a representative molecular weight and vapour pressure for the preparation/mixture as a whole, which may be uncertain for many preparations/mixtures.

The first stage is to estimate the mole fraction of the component in the solid or liquid mixture/preparation. If this information is not known, it can be estimated (very approximately) using the following method.

$$x_{comp} = \frac{f_{comp}}{MW_{comp} \times \left[\left(\frac{f_{comp}}{MW_{comp}} \right) + \left(\frac{1 - f_{comp}}{MW_{prep}} \right) \right]}$$ Equation 2

$$x_{prep} = 1 - x_{comp}$$ Equation 3

The partial pressures of the preparation and specific component in the vapour can then be estimated from Raoult’s law.

$$P_{comp} = x_{comp} \times VP_{comp}$$ Equation 4

$$P_{prep} = x_{prep} \times VP_{prep}$$ Equation 5

The mole fraction of the additive in the vapour can then be estimated as follows.

$$y_{comp} = \frac{P_{comp}}{\left(P_{comp} + P_{prep}\right)}$$ Equation 6

Explanation of symbols:			
x_{comp}	Mole fraction of the component in the solid or liquid preparation/mixture	[-]	
x_{prep}	Mole fraction of the other components in the mixture/preparation	[-]	
f_{comp}	Weight fraction of the specific component in the preparation or mixture	[-]	Substance-specific information
MW_{comp}	Molecular weight of the specific component	[g mol^{-1}]	Substance-specific information
MW_{prep}	Average or typical molecular weight for the preparation/mixture	[g mol^{-1}]	Substance-specific information
P_{comp}	Approximate partial vapour pressure of the specific component	[Pa]	
P_{prep}	Approximate partial vapour pressure of the other components of the mixture/preparation	[Pa]	
VP_{comp}	Vapour pressure of the specific component	[Pa]	Substance-specific information
VP_{prep}	Representative vapour pressure of the mixture/preparation	[Pa]	Substance-specific information
y_{comp}	Mole fraction of the specific component in the vapour	[-]	

As a general point it should be noted that much work has been carried out on the emissions from petroleum products during transportation, distribution and storage. For example, a large amount of information on losses during storage is available from the American Petroleum Institute (API). This information forms the basis of methods used by the United States Environmental Protection Agency. The details of the calculation methods are copyright of the API and so have not been reproduced here, but they are outlined in Chapter 7 of the *Compilation of air pollutant emission factors AP-42* (USEPA). The methods are also implemented in a freely available computer program produced by USEPA called TANKS (version 4)[24]. These methods cover the emissions to air during filling and emptying, and breathing losses associated with floating roof tanks (with external, covered or internal floating roofs) and fixed roof tanks (vertical tanks and horizontal tanks), and can also investigate the effects of various emission reduction measures on the estimated emissions.

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[24] Available from: http://www.epa.gov/ttn/chief/software/tanks/index.html.

These methods are recommended by the UK Institute of Petroleum for estimating emissions of petroleum products from such tanks, and could also be used for estimating emissions of other chemicals from storage tanks. Similarly, the losses from transportation and marketing of petroleum liquids (including loading rail, road and marine tankers) have been considered in Chapter 5.2 of AP-42. This document should be consulted for further details of the methods used. Other methods, notably those in the EMEP/CORINAIR Handbook (European Environment Agency, 2004) and the Environment Australia National Pollutant Inventory (NPI) Emission Estimation Techniques Manuals (NPI, 1999a, 1999b) are also available (some of these methods are based on the AP-42 methodologies) and should also be consulted.

In the following sections, it is indicated where the API/USEPA/TANKS methods can be used for a site-specific assessment but alternative, simplified methods are also given where available and appropriate.

In addition to the TANKS methodology, methods of estimating emissions from some of the operations covered are being developed by USEPA. For example, OECD (2005) indicates that a method known as the penetration model is being developed by the USEPA Office of Pollution Prevention and Toxics (OPPT) for estimating the emissions from cleaning of containers during the blending of fragrances, and it is likely that such methods could be applied to other situations. Few details of this methodology are currently given in OECD (2005), but it is understood that this methodology is being incorporated into the ChemSTEER software[25] that is under development. This software may provide a further useful source of information for estimating emissions from transport and storage of chemicals in general.

Emissions from the filling of vehicle fuel tanks are not covered in this ESD. However, many methods are available that allow both total hydrocarbon emissions and speciated hydrocarbon emissions to be estimated from this source (for example, Institute of Petroleum, 2000; USEPA AP-42, Chapter 7, amongst others). These sources should be consulted for details of the calculation methods.

5.2 Size of operation

The typical sizes of the various transport and storage systems considered are shown in Table 0.1. It should be noted that certain size limitations apply to the carriage of some dangerous substances (see Table 0.2 and Table 0.3 **Allowed packaging and maximum amounts of dangerous solids that can be transported by road by packaging type (UN, 2004a)**

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
Single packaging	Drums – non-removable head – steel, aluminium, other metal, plastics	400 kg	400 kg	400 kg

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[25] A beta version of the program is available from http://www.epa.gov/opptintr/exposure/docs/chemsteer.htm.

Packaging		Maximum capacity/net mass		
		Packing group I	Packing Group II	Packing Group III
	Drums – removable head – steel, aluminium, other metal, plastic	400 kga	400 kga	400 kg2
	Drums – fibre and plywood	400 kga	400 kga	400 kga
	Jerricans – non-removable head – steel, aluminium, plastic	120 kg	120 kg	120 kg
	Jerricans – removable head – steel, aluminium, plastic	120 kga	120 kga	120 kga
	Boxes – steel, aluminium, natural wood, plywood, reconstituted wood, natural wood with sift-proof walls, fibreboard and solid plastic	Not allowed	400 kga	400 kga
	Bags	Not allowed	50 kga	50 kga
Composite packaging	Plastics receptacle with outer steel, aluminium or plastics drum	400 kg	400 kg	400 kg
	Plastics receptacle with outer plywood or fibre drum	400 kga	400 kga	400 kga
	Plastics receptacle with outer steel or aluminium crate or box, or solid plastics box	75 kg	75 kg	75 kg
	Plastics receptacle with outer wooden, plywood or fibreboard box	75 kga	75 kga	75 kga
	Glass receptacle with outer steel, aluminium drum or with outer steel or aluminium crate or box, or with outer solid plastics packaging	75 kg	75 kg	75 kg
	Glass receptacle with outer plywood or fibre drum or with outer wooden or fibreboard box or with outer wickerwork hamper or expanded plastics packaging	75 kga	75 kga	75 kga
IBCs	Metal	3,000 litres	3,000 litres	3,000 litres
	Flexiblea, rigid plastic, compositea, fibreboarda and woodena	1,500 litres	3,000 litres	3,000 litres

Note: a) This type of packaging cannot be used for transporting substances that may become liquid during carriage. This is defined as those substances with a melting point ≤ 45°C.

4.2.2 Generic approach

A key part of developing an emission scenario is the identification of relevant packaging types and transport and storage systems that could be used for a given chemical of interest. From the discussion in Section 0 it can be seen that a wide range of packaging types could be used for any given chemical, and this needs to be reflected in the emission scenarios generated. However, it may not always be practical to consider every eventuality for a given chemical and so there needs to be some method for identifying the most relevant combinations of transport, packaging and storage systems that apply to a given situation.

in Section 0) and these should be taken into account when considering the information in Table 0.1 in relation to a specific substance.

The size or number of transport and storage systems appropriate to a given site will depend on the amount of chemical produced or used at a site, and the number of days of operation.

Table 0.1 Typical sizes of transport and storage systems

System	Typical size (default) M_s (mass of substance) or V_s (volume of substance)	Other size	Types of chemical/comment
Road tankers	25,000 kg (25 tonnes) (44,000 kg gross weight)	Smaller tankers (e.g. 18,000 kg gross weight) or multi-compartment tankers can be used.	Used for many types of liquids, viscous liquids and solids
Rail tankers	Up to 130,000 litres (~130 tonnes)		Used to transport petroleum products from refineries to distribution terminals. Not commonly used for other chemical products in UK. Will be dedicated to a specific product.
Ocean/sea (ship) tankers	1.1×10^7-5.6×10^8 litres (3-147 million US gallons)		Information from USEPA (1995b)
Barge tankers	1.6×10^6-5.6×10^6 litres (420,000-1,470,000 US gallons)		Information from USEPA (1995b)
Pipelines	Directly related to amount of chemical used and/or transported		Used widely for the transport and distribution of petroleum (and natural gas products) in the UK. Around 30 million litres of petrol, diesel and jet fuel are transported by pipeline each year in the UK. Dedicated pipelines are also used at many chemical production facilities.
IBCs	1,000 kg 1,250 litres	400-2,000 litres or 225-2,270 kg Up to 3,000 litres for hard IBCs and up to 1,500 litres for	Used for many types of liquids, viscous liquids and solids.

System		Typical size (default) M_s (mass of substance) or V_s (volume of substance)	Other size	Types of chemical/comment
			flexible IBCs Most common 275-330 US gallon (1,040-1,250 litres)	
Drums	Steel	205 litres	49-416 litres	Used for many types of liquids, viscous liquids and solids. The 205 litre drum is by far the most common size used in the UK and Europe.
	Plastic	205 litres		Used for many types of liquids, viscous liquids and solids. The 205 litre drum is by far the most common size used in the UK and Europe
	Composite	205 litres	9.5-205 litres	Composite drums consist of a semi-rigid plastic liner and either a steel or fibre outer. Used for many types of liquids, viscous liquids and solids. The 205 litre drum is by far the most common size used in the UK and Europe.
	Fibre	250 kg net weight	Typically 4-380 litres, but can be up to around 450 litres (net weight up to around 400 kg)	Mainly used for transport of dry, granular solids and semi-solids, but can be used to transport liquids when used in combination with a suitable liner and/or coating.
Bags	Supersacks or big bags	1,000 kg		Becoming increasingly popular for transport of solid chemicals.
	Textile	25 kg		Solids (e.g. mainly agricultural crops and animal feeds, little used for chemicals).
	Laminated textile	25 kg		Solids (e.g. petrochemicals, drugs, insecticides, fertilizers). Generally used for products with high intrinsic value.

System		Typical size (default) M_s (mass of substance) or V_s (volume of substance)	Other size	Types of chemical/comment
	Multiwall paper	25 kg		Solids (e.g. agricultural products, certain chemicals, food and rock products).
	Plastic	25 kg		Solids (e.g. chemicals).
Storage tanks	External floating roof			Used for liquids.
	Vertical fixed roof			Used for liquids.
	Above ground horizontal atmospheric	≤ 150,000 litres		Used for liquids.
	Horizontal pressurised			Used for liquids (and gases) with high vapour pressures.
	Vertical pressurised	≤ 1,750,000 litres		Used for liquids (and gases) with high vapour pressures.
	Spheres (pressurised)	≤ 3,500,000 litres		Used for liquids (and gases) with high vapour pressures.
	Mounded storage (pressurised)	≤ 3,500,000 litres		Typically used for storage of liquefied petroleum gas. A given site may have several tanks side-by-side
	Variable vapour space			Used for vapours at or very close to atmospheric pressure.
	Refrigerated storage			Used for large-scale storage of liquefied gases such as ammonia, chlorine, liquefied petroleum gas.
	Underground horizontal	≤ 50,000 litres		Used for storage of gasoline, diesel and other fuels at the point of use.
	Mined caverns (atmospheric)	100,000,000 litres	Typically in the range 50,000,000 to 580,000,000 litres	Used for hydrocarbon products (e.g. crude oil, liquefied petroleum gas, gasoline, diesel fuel, light fuel oil, heavy fuel oil) that are less dense than water. Most mined caverns are of the pressurised type.

System		Typical size (default) M_s (mass of substance) or V_s (volume of substance)	Other size	Types of chemical/comment
	Mined caverns (pressurised)	100,000,0000 litres	As for mined caverns (atmospheric) but can be as small as 8,000 m^3 for liquefied petroleum gas.	As for mined caverns (atmospheric) but can also be used to store pressurised liquefied gas.
	Salt leach caverns	100,000,000 litres	Typically 90,000-450,000 litres	Used for hydrocarbon products (e.g. crude oil, diesel oil, gasoline, naphtha, liquefied pressurised gases).
Open storage (bulk)				Used for storage in heaps of larger quantities of bulk solids that are not seriously affected by exposure to weather (e.g. coal, gypsum, ore, scrap, sand).
Silos and bunkers			Up to around 10,000,000 kg	Silos used for storage of dry and/or fine solid materials. Bunkers normally used for storage of coarser solid materials.

For a given site, the amount of substance produced or used, and number of days of operation, can either be obtained directly from the producer/user or, failing this, can be estimated using the A- and B-tables given in Appendix I of Chapter 3 of the EU Technical Guidance Document (TGD) (European Commission, 2003c).

$$N_{load} = \frac{Q_{total}}{M_s} = \frac{Q_{total} \times 1{,}000}{V_s \times RHO_s} = \frac{V_{total}}{V_s} \qquad \text{Equation 7}$$

$$N_{load\_ave} = \frac{N_{load}}{N_{days}} \qquad \text{Equation 8}$$

Explanation of symbols:			
N_{load}	Number of unit loads (events) transported each year	[number of events year^{-1}]	
N_{load_ave}	Average number of unit loads (events) transported or used per day	[number of events day^{-1}]	
N_{days}	Number of days operation per year	[days year^{-1}]	Substance-specific information or A- and B-Tables from the TGD
Q_{total}	Total quantity of substance (or preparation) produced or used at a site	[kg year^{-1}]	Substance-specific information or A- and B-Tables from the TGD
V_{total}	Total volume of substance (or preparation) produced or used at a site	[litres year^{-1}]	Substance-specific information
M_s	Mass of substance (or preparation) per tanker or per packaging type (e.g. drum, IBC, bag)	[kg unit load^{-1}]	Table 0.1
V_s	Volume of substance (or preparation) per tanker or per packing type (e.g. drum, IBC)	[litres unit load^{-1}]	Table 0.1 and Section 0.
RHO_s	Density of substance (or preparation)	[kg m^{-3}]	Substance-specific information
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	

If N_{load_ave} is < 1 this implies that daily delivery is not appropriate for the site and so weekly or monthly delivery should be considered. In this case, the average number of loads transported on the particular delivery day will be $N_{load\_ave} \times 5$ (for weekly delivery) or $N_{load\_ave} \times 20$ (for monthly delivery) (both assuming five working days per week). Of course, other delivery cycles may also occur but it is not possible to estimate these in a generic fashion (in these cases, the minimum number of days between deliveries would be $1/N_{load\_ave}$).

For IBC and drum cleaning operations, it is also necessary to estimate the number of drums or IBCs containing a specific substance that may be cleaned at a site on a given day. This is difficult to estimate as it requires knowledge of both the total number of drums or IBCs cleaned on a site per day and an estimate of the fraction of the total number that contains any specific chemical. Both of these pieces of information are not readily available.

For the United States, it has been reported that a typical drum reconditioning plant may clean around 1,000 drums per day (see Section 0). No figures are available on the typical number of IBCs cleaned on a site per day, but it would be expected to be lower than for drums owing to the larger size of IBCs. Here it is assumed that 100 IBCs per day is an appropriate figure.

Assuming there are eight major reconditioners of plastic and steel drums and 13 major reconditioners of IBCs in the United Kingdom (see Section 0), then the total number of drums and IBCs reconditioned at these sites can be estimated very roughly as 4,800,000 drums and 390,000 IBCs per year, assuming 300 days per year of operation.

In order to estimate the number of drums or IBCs that are used to carry a specific chemical, knowledge is needed on the proportion of the total tonnage that is carried in drums and IBCs. This information is expected to be very substance specific and cannot be easily estimated. However, for the needs of the emission scenario, it may not be necessary to have precise figures on this owing to the large number of assumptions made in the emission scenarios. Thus, the approach outlined below is based on the maximum theoretical number of drums (Equation 9) or IBCs (Equation 10) that could be used to contain the substance, assuming that it is all carried in either drums or IBCs and not a mixture of the two.

$$N_{s\_drum} = \frac{Q_{total\_reg} \times 1{,}000}{RHO_s \times V_{drum}} = \frac{V_{total\_reg}}{V_{drum}}$$ Equation 9

$$N_{s\_IBC} = \frac{Q_{total\_reg} \times 1{,}000}{RHO_s \times V_{IBC}} = \frac{V_{total\_reg}}{V_{IBC}}$$ Equation 10

$$F_{total\_drum} = \frac{N_{s\_drum}}{N_{total\_drum}}$$ Equation 11

$$F_{total\_IBC} = \frac{N_{s\_IBC}}{N_{total\_IBC}}$$ Equation 12

Explanation of symbols:			
N_{s_drum}	Number of drums containing the substance (or preparation) used in a region/country	[-]	
N_{s_IBC}	Number of IBCs containing the substance (or preparation) used in a region/country	[-]	
Q_{total_reg}	Total amount of substance (or preparation) produced or used in a region/country	[kg year^{-1}]	Substance-specific information

Explanation of symbols:			
V_{total_reg}	Total volume of substance (or preparation) produced or used in a region/country	[litres year^{-1}]	Substance-specific information
V_{drum}	Volume of drum used	[litres]	Default = 205 litres
V_{IBC}	Volume of IBC used	[litres]	Default = 1,000 litres
RHO_s	Density of substance (or preparation)	[kg m^{-3}]	Substance-specific information
F_{total_drum}	Fraction of total drums reconditioned that contain the substance (or preparation)	[-]	
F_{total_IBC}	Fraction of total IBCs reconditioned that contain the substance (or preparation)	[-]	
N_{total_drum}	Total number of drums reconditioned in a region/country	[-]	Default = 4,800,000
N_{total_IBC}	Total number of IBCs reconditioned in a region/country	[-]	Default = 390,000
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	

5.3 Emission scenarios based on emission factors

The available emission factors for processes relevant for transport and storage of chemicals are discussed in Section **Error! Reference source not found.** for the various transport, packaging and storage systems considered. For substances where an emission factor is available, an emission scenario can be developed using the general approach outlined below.

$$E_{process} = \frac{EF_{process} \times Q_{total}}{N_{days}} \qquad \text{Equation 13}$$

Explanation of symbols:			
$E_{process}$	Emission per event from a given process	[kg event^{-1}]	
$EF_{process}$	Emission factor for the process	[kg kg^{-1}] or [kg litre^{-1}]	Substance-specific information or Section **Error! Reference source not found.**
Q_{total}	Mass (or volume) of substance used at the site	[kg year^{-1}] or [litres year^{-1}]	Substance-specific information or A- and B-Tables of the TGD
N_{days}	Number of days of operation	[days year^{-1}]	Substance-specific information or A- and B-Tables of the TGD

5.4 Generic emission scenarios for filling

5.4.1 Vapours

It should be noted that the generic scenarios outlined in the following sections do not take account of any emission control measures that may be routinely used, such as local exhaust ventilation (LEV). Although LEV will be commonplace for many operations involving filling drums, IBCs and storage tanks, as a result of legislation for the protection of workers, such emission control measures do not necessarily result in reduced emissions to the environment. For example, LEV in its simplest form merely results in the contaminated air within the worker environment being transferred to the outdoor environment.

Exceptions to this occur where the LEV also incorporates some types of treatment measures, for example activated carbon adsorption of vapours or incineration of the vapours. In these cases, a substantial reduction in emissions compared with the generic cases would be expected. It is recommended that, at sites where it is known that the LEV used incorporates such measures, this should be taken into account in the estimated emissions from the site. In the absence of actual data on the efficiencies of the system at the site, the abatement efficiencies outlined in Table 0.2 could be used as a starting point. It should be born in mind that the actual efficiency obtained in any given situation will depend on the specific circumstances at the site in question.

Table 0.2 Suggested emission abatement efficiencies for LEV

Measure	Suggested abatement efficiency	Emission reduction factor[a]
LEV alone	0%	1
LEV plus carbon adsorption	90%	10
LEV plus incineration	99%	100
Closed system	100%	Near zero emission

Note: a) The resulting emissions calculated using the following approaches should be reduced by this factor at sites where these measures apply.

It should also be noted that essentially closed systems can be used for emptying various types of storage tank, drums and IBCs. These may be particularly relevant for the handling of highly toxic substances. Emissions from such systems are expected to be near zero.

Emissions from the filling process are closely linked with the associated emissions from emptying (for example, a storage tank may be filled by emptying a road tanker) and so it is not always possible, nor desirable, to disaggregate the emissions from the two processes. If a specific emission scenario is needed for emptying of a transport or storage system, then the following approach could be taken. However, caution needs to be taken to ensure that the emissions estimated for emptying are not already accounted for in the subsequent filling losses for the receiving vessel.

5.4.1.1 Road tankers

The Institute of Petroleum (2000) gives recommended methods for estimating the emissions of volatile substances from loading of oil and petroleum products into road tankers. The method outlined below is adapted from these methods.

For any given substance, the emission to air is dependent on the method of filling (top loading/splash loading or bottom loading). For substances that use dedicated road tankers, the emissions during filling also depend on whether the tanker is unloaded using vapour balancing[26] (see Section 0). The methods are appropriate for uncontrolled loading operations, where the vapours vent directly to the atmosphere.

Top loading – with no vapour balancing at the site of delivery

$$E_{loading\_top\_no\_vapour\_balance} = 0.94 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 14}$$

Bottom loading – with no vapour balancing at the site of delivery

$$E_{loading\_bottom\_no\_vapour\_balance} = 0.86 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 15}$$

Loading – with vapour balancing at the site of delivery

$$E_{loading\_vapour\_balance} = 2.28 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 16}$$

Explanation of symbols:			
$E_{loading}$	Emission per event to air from filling the tanker	[kg event^{-1}]	
M_s	Mass of substance added to tank. This is taken to be equal to the net weight of the tanker for complete filling of the tanker.[a]	[kg unit load^{-1}]	Table 0.1. Default = 25,000 kg
RHO_s	Density of substance[a]	[kg m^{-3}]	Substance-specific information
VP_s	Vapour pressure for substance (at filling temperature)[b]	[Pa]	Substance-specific information
1×10^5	Conversion factor between Pa and atmospheres	[Pa atm^{-1}]	

Note: a) The volume of substance (in m^3) can be used to replace the term M_s/RHO_s in the equation if known.

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[26] Vapour balancing results in higher concentrations of vapour being present in the empty tanker which may then be emitted when the tanker is re-filled.

b) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

The above equations can be used to estimate the emission to air during a single loading event. The total yearly emissions from loading can be estimated using a similar method with the total mass of substance (M_s) transported per year in the relevant equation.

The emissions from road tankers during transportation can be considered to be negligible (Institute of Petroleum, 2000).

Alternative methods for estimating the emissions of petroleum products from this source are given in Chapter 5.2 of AP-42 (USEPA).

5.4.1.2 Rail tankers

The Institute of Petroleum (2000) recommends methods for estimating the emissions of volatile substances from loading of oil and petroleum products into rail tankers. The method outlined below is adapted from these methods. Two sources of emission are considered. The first is the emissions from the loading operation itself, and the second is from the loading hatches from the rail tank. These hatches may be opened prior to the rail tanker entering the loading facility and closed only after the rail tanker has left the loading facility. The emissions assume dedicated service, which would be typical for rail tankers. The methods are appropriate for uncontrolled loading operations, where the vapours vent directly to the atmosphere.

Loading losses

$$E_{loading} = 1.05 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 17}$$

Losses from open hatches prior to and post loading

$$E_{hatch} = 0.03 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 18}$$

Explanation of symbols:			
$E_{loading}$	Emission per event to air from filling the tanker	[kg event^{-1}]	
E_{hatch}	Emission per event to air from open hatches before and after loading	[kg event^{-1}]	
M_s	Mass of substance added to tank. This is taken to be equal to the net weight of the tanker for complete filling of the tanker[a].	[kg unit load^{-1}]	Table 0.1. Default = 130,000 kg
RHO_s	Density of substance[a]	[kg m^{-3}]	Substance-specific information

Explanation of symbols:			
VP_s	Vapour pressure for substance (at filling temperature)[b]	[Pa]	Substance-specific information
1×10^5	Conversion factor between Pa and atmospheres	[Pa atm^{-1}]	

Note: a) The volume of substance (in m^3) can be used to replace the term M_s/RHO_s in the equation if known.

b) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

The above equations can be used to estimate the emission to air during a single loading event. The total yearly emissions from loading can be estimated using a similar method with the total mass of substance (M_S) transported per year by this method in the relevant equation.

The emissions from rail tankers during transportation can be considered to be negligible (Institute of Petroleum, 2000).

Alternative methods for estimating the emissions of petroleum products from this source are given in Chapter 5.2 of AP-42 (USEPA).

5.4.1.3 Ship tankers

The Institute of Petroleum (2000) offers recommended methods for estimating the emissions of volatile substances from loading of oil and petroleum products into sea going vessels and inland waterway barges. The method outlined below is adapted from these methods.

Emissions from this source depend on the volatility of the previous cargo carried (in this method, volatile is considered as a vapour pressure of greater than 1×10^4 Pa at the temperature of filling) and the tank treatment prior to filling.

The method given in Institute of Petroleum (2000) estimates the total hydrocarbon emissions from loading of petroleum products and so does not consider explicitly whether the previous cargo was (or contained) the same substance as is being loaded. Therefore, the method needs to be used in a slightly modified way here. For chemicals where the cargo being loaded is the same as the cargo previously carried, and the substance can be considered volatile within the definition used in the method (vapour pressure > 1×10^4 Pa), then equations for previous cargo volatile (Equations 19 to 22 and Equations 24 to 25) should be used, depending on the mode of transport and cleaning method. For other substances where the cargo previously carried is not the same as that currently being loaded, then Equation 23 (ships) or Equation 26 (barges) are recommended.

Sea going vessels – previous cargo volatile – uncleaned tanks

$$E_{loading\_sea\_volatile\_uncleaned} = 0.9 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1\times10^5}$$ Equation 19

Sea going vessels – previous cargo volatile – ballasted tanks[27]

$$E_{loading\_sea\_volatile\_ballasted} = 0.59 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 20

Sea going vessel – previous cargo volatile – cleaned

$$E_{loading\_sea\_volatile\_cleaned} = 0.51 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 21

Sea going vessel – previous cargo volatile – gas freed

$$E_{loading\_sea\_volatile\_gas\_freed} = 0.24 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 22

Sea going vessel – previous cargo any – typical overall

$$E_{loading\_sea\_typical} = 0.61 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 23

Barge – previous cargo volatile – uncleaned

$$E_{loading\_barge\_volatile\_uncleaned} = 1.29 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 24

Barge – previous cargo volatile – gas freed

$$E_{loading\_barge\_volatile\_gas\_freed} = 0.7 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 25

Barge – previous cargo any – typical overall

$$E_{loading\_barge\_typical} = 1.17 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 26

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[27] Tanks ballasted with seawater.

Explanation of symbols:			
$E_{loading}$	Emission per event to air from filling the tanker	[kg event^{-1}]	
M_s	Mass of substance added to tanker[a]	[kg unit load^{-1}]	Substance-specific information or Table 0.1
RHO_s	Density of substance[a]	[kg m^{-3}]	Substance-specific information
VP_s	Vapour pressure for substance (at filling temperature)[b]	[Pa]	Substance-specific information
1×10^5	Conversion factor between Pa and atmospheres	[Pa atm^{-1}]	

Note: a) The volume of substance (in m^3) can be used to replace the term M_s/RHO_s in the equation if known.
b) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

As ocean-going ships may be in transit for many days or weeks, emissions can also occur during transport from temperature and pressure changes in the cargo tanks (breathing losses). The Institute of Petroleum (2000) gives the following recommended method for estimating the emissions of volatile substances during the transport of oil and petroleum products in sea going vessels.

$$E_{breathing\_sea\_transport} = 0.125 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1\times10^5} \times t \qquad \text{Equation 27}$$

Explanation of symbols:			
$E_{breathing}$	Emission per event to air from filling the tanker	[kg voyage^{-1}]	
M_s	Mass of substance added to tanker[a]	[kg unit load^{-1}]	Substance-specific information or Table 0.1.
RHO_s	Density of substance[a]	[kg m^{-3}]	Substance-specific information
VP_s	Vapour pressure for substance (at filling temperature)[b]	[Pa]	Substance-specific information
t	Time of transit	[days]	Substance-specific information
1×10^5	Conversion factor between Pa and atmospheres	[Pa atm^{-1}]	

Note: a) The volume of substance (in m^3) can be used to replace the term M_s/RHO_s in the equation if known.
b) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

Alternative methods for estimating the emissions of petroleum products from this source are given in Chapter 5.2 of AP-42 (USEPA).

5.4.1.4 Storage tanks

The USEPA TANKS model (or Chapter 7 of USEPA AP-42) can be used to estimate the volatile emissions during the filling of storage tanks for site-specific situations.

An alternative, simplified method for estimating the emissions of volatiles from the filling of storage tanks is presented in NPI (1999a). The method assumes that the main source of emissions results from the displacement of saturated vapour during the addition of the substance to the storage tank (or any other vessel for that matter), and thus that the volume of vapour released is equal to the volume of liquid added to the tank.

The first step is to estimate the mole fraction of the substance in the atmosphere of the tank. This can be estimated using the following equation (and can be applied to mixtures or pure substances):

$$y_{comp} = x_{comp} \times \left(\frac{VP_{comp}}{P} \right) \qquad \text{Equation 28}$$

The total number of moles of gas emitted from the tank can be estimated from the ideal gas law:

$$n_{total} = \frac{P}{R \times T} \times \frac{V_s}{1{,}000} \qquad \text{Equation 29}$$

The mass of the substance emitted to air can thus be estimated as:

$$E_{tank\_filling\_comp} = n_{total} \times y_{comp} \times \frac{MW_{comp}}{1{,}000} = \frac{P \times V_s}{R \times T \times 1{,}000} \times x_{comp} \times \frac{VP_{comp}}{P} \times \frac{MW_{comp}}{1{,}000} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1{,}000}$$

Equation 30

Explanation of symbols:			
$E_{tank\_filling\_comp}$	Emission per event to air of chemical (component) from filling the tank	[kg event^{-1}]	
P	Pressure of tank	[Pa]	Default = 1.01×10^5 Pa (atmospheric pressure)
V_s	Volume of substance (mixture/preparation) added to tank	[litres unit load^{-1}]	Substance-specific data or Table 0.1.
R	Ideal gas constant	[J K^{-1} mol^{-1}]	8.314
T	Temperature	[K]	Default = 298K
x_{comp}	Mole fraction of chemical (component) in the liquid	[-]	Default = 1 for pure substances. For mixtures, substance-specific data or Equation 2
y_{comp}	Mole fraction of the chemical (component) in the atmosphere of the tank	[-]	
VP_{comp}	Vapour pressure of chemical (component) at temperature T	[Pa]	Substance-specific data
MW_{comp}	Molecular weight of chemical (component)	[g mole^{-1}]	Substance-specific data
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	
1,000	Conversion factor between kg and g	[g kg^{-1}]	

The Institute of Petroleum (2000) gives recommended methods for estimating the emissions of volatile substances from loading petroleum products into underground storage tanks at service stations. The method outlined below is adapted from Institute of Petroleum (2000).

Underground storage tanks without vapour balancing

$$E_{tank\_filling\_underground\_storage\_no\_vapour-balance} = 2.44 \times \frac{V_s}{1{,}000} \times \frac{VP_s}{1\times10^5} \quad \text{Equation 31}$$

Underground storage tanks with vapour balancing

$$\mathrm{E}_{\mathrm{tank\_filling\_underground\_storage\_vapour\ \ balance}} = 0.11 \times \frac{\mathrm{V_s}}{1{,}000} \times \frac{\mathrm{VP_s}}{1\times10^5} \quad \text{Equation 32}$$

Explanation of symbols:			
$E_{tank\_filling}$	Emission per event to air from filling the tank	[kg event^{-1}]	
V_s	Volume of substance added to tank	[litres unit load^{-1}]	Substance-specific data or Table 0.1.

Explanation of symbols:			
VP_s	Vapour pressure of substance at filling temperature[a]	[Pa]	Substance-specific data
1×10^5	Conversion factor between Pa and atmosphere	[Pa atm^{-1}]	
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	

Note: a) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

5.4.1.5 Drums and IBCs

No specific emission scenario has been identified in the literature relating to vapour emissions during the filling of drums. As a worst case approach, it could be assumed that the air within the drum or IBC becomes saturated with the substance, and that this is then displaced as the drum is filled. This is in principle very similar to the NPI (1999a) method outlined in 0 for storage tanks. In this case, the emission to air can be estimated using the following equation. The equation is applicable to both pure substances and mixtures/preparations.

$$E_{IBC/drum\_filling\_comp} = n_{total} \times y_{comp} \times \frac{MW_{comp}}{1,000} = \frac{P \times V_s}{R \times T \times 1,000} \times x_{comp} \times \frac{VP_{comp}}{P} \times \frac{MW_{comp}}{1,000} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1,000} \times \frac{MW_{comp}}{1,000}$$

Equation 33

Explanation of symbols:			
$E_{IBC/drum\_filling\_comp}$	Emission per event to air of chemical (component) from filling the IBC or drum	[kg event^{-1}]	
P	Pressure of drum/IBC	[Pa]	Default = 1.01×10^5 Pa (atmospheric pressure)
V_s	Volume of substance (mixture or preparation) added to drum/IBC	[litres unit load^{-1}]	Substance-specific data or Table 0.1.
R	Ideal gas constant	[J K^{-1} mol^{-1}]	8.314
T	Temperature	[K]	Default = 298K
x_{comp}	Mole fraction of chemical (component) in the liquid	[-]	Default = 1 for pure substances. For mixtures, substance-specific data or Equation 2
y_{comp}	Mole fraction of the chemical (component) in the atmosphere of the tank	[-]	
VP_{comp}	Vapour pressure of chemical (component) at temperature T	[Pa]	Substance-specific data

Explanation of symbols:			
MW_{comp}	Molecular weight of chemical (component)	[g $mole^{-1}$]	Substance-specific data
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	
1,000	Conversion factor between kg and g	[g kg^{-1}]	

5.4.2 Solids

For solid loading in tankers, drums, IBCs, bags and silos, it is more difficult to estimate the emissions from the process, and little information appears to have been published on this aspect. A possible approach assumes that as the tanker/drum/IBC/bag is loaded, air containing particulates/dust is expelled and has the potential to enter the environment. This is outlined below.

The method assumes that expelled air from the tanker/container/bag is filtered, and that the maximum concentration in the filtered air is between 1 and 10 mg/m^3 (see Section 0). In the absence of any other data, a figure of 1 mg/m^3 is assumed for solids with a low dust generation potential (for example, with a particle size of >40 μm) and a figure of 10 mg/m^3 is assumed for solids with a high dust generation potential.

$$Vol_{air\_disp} = \frac{M_s}{RHO_s} \times D \qquad \text{Equation 34}$$

$$E_{loading\_dust} = \frac{Vol_{air\_disp} \times Conc_{air}}{1 \times 10^6} \qquad \text{Equation 35}$$

Explanation of symbols:			
$E_{loading\_dust}$	Emission per event to air from filling	[kg $event^{-1}$]	
M_s	Mass of substance added to tanker/drum/IBC/bag/silo. This is taken to be equal to the net weight of the vessel for complete filling of the vessel.[a]	[kg unit $load^{-1}$]	Table 0.1
Vol_{air_disp}	Volume of air displaced during filling of tanker, drum.	[m^3]	
RHO_s	Bulk density of substance[a]	[kg m^{-3}]	Substance-specific information
D	Dispersion factor to take account of the fact that the volume of air displaced may be higher than the volume of substance added	[-]	Suggested default in the range 1-10,000 (see discussion below)
$Conc_{air}$	Concentration of substance in air[b]	[mg m^{-3}]	Substance-specific information or default = 1

Explanation of symbols:			
			mg/m^3 for particle size > 40 µm or 10 mg/m^3 for particle size < 40 µm
1×10^6	Conversion factor between kg and mg	[mg kg^{-1}]	

Note: a) The volume of solid added (in m^3) can be substituted for the term M_s/RHO_s if known.
b) For mixtures/preparations, the concentration of the specific component of interest ($Conc_{air}\times f_{comp}$) should be used, where f_{comp} = weight fraction of the specific component in the preparation or mixture.

As indicated above, these calculations assume some sort of dust filtering system will be present during the loading operation. Actual emissions in cases where no such system is used may be higher, but it is not possible to estimate such emissions directly. As a worst case approach, it could be assumed that the unfiltered emissions are a factor of 10 higher than the filtered emissions (that is, the filtering efficiency is around 90 per cent).

Although the major source of emission is likely to be initially dust to the air, particulates would be expected to settle rapidly within the workplace and so could lead to emissions to other phases, such as waste water or solid disposal, as a result of cleaning down of surfaces, floors and so on.

A key assumption in the approach is that the volume of air displaced during filling of the vessel can be related to the amount of substance added. In reality, the volume of air displaced will depend on a number of factors including the drop height during filling, the rate of filling and the ventilation rate (either natural or forced) in the filling area. Equation 35 can be used to effectively define an emission factor for the loading process. For example, using M_s = 1,000 kg (one tonne), RHO_s = 1,000 kg/m^3, D = 1 and $Conc_{air}$ = 10 mg/m^3, an approximate emission factor of 1×10^{-5} kg/tonne loaded can be estimated for the situation where emission control measures such as filters are present (the corresponding emission factor without such controls would be 1×10^{-4} kg/tonne).

Comparing these factors with the limited published emission factor data (see Table 0.3 for bagging) shows that actual emission factors are generally around a factor of 1,000 higher than estimated here. This suggests that the value of the D used in the calculation may need to be up to around 1,000 depending on the application.

If monitoring data is available for the filling station (for example, occupational exposure data), this can be used in the approach to represent $Conc_{air}$.

5.4.3 Liquids

There is the potential for loss of liquids from the filling of tankers, drums and IBCs as a result of spills or drips. As discussed in Section 0, current best practice is that such operations are carried out in bunded areas or use some other type of collection and containment system, thus minimising the potential for emission to the environment if such drips or spills occur. However, if such measures are not in place then the potential for emissions to the environment does exist. It is not currently possible to estimate the magnitude of these emissions, as they are likely to depend on the specific operating practice at the site of interest.

5.5 Emission scenarios for emptying

5.5.1 Vapours

No specific emission scenarios were found for vapour emissions during emptying of tankers, drums, IBCs and storage tanks. Emissions from these processes are closely linked with the associated filling emissions (for example, a road tanker may be emptied into a storage tank) and so it is not always possible, nor desirable, to disaggregate the emissions from the two processes. If a specific emission scenario is needed for emptying of a transport or storage system, then the following approach could be taken. However, caution needs to be taken to ensure that the emissions estimated for emptying are not already accounted for in the subsequent filling losses for the receiving vessel.

There is also overlap here with the subsequent processing stages for a chemical, for example when the substance is emptied from a container into a reaction vessel for subsequent reaction. This scenario does not consider the emissions resulting from filling of the reaction vessel, as this is considered to be part of the subsequent process losses for the chemical. This distinction needs to be considered when using this ESD in conjunction with other emission estimates or measurements relating to the processing of the chemical, in order to avoid double counting of emissions.

The main (and probably only) assumption that can be made is that as the vessel/tanker is emptied, the air within the vessel becomes saturated with the substance, and the substance-saturated air is subsequently released. Thus, broadly the same approach as outlined in Sections 0 and 0 can be taken.

$$E_{emptying\_comp} = n_{total} \times y_{comp} \times \frac{MW_{comp}}{1000} = \frac{P \times V_s}{R \times T \times 1{,}000} \times x_{comp} \times \frac{VP_{comp}}{P} \times \frac{MW_{comp}}{1000} =$$
$$\frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1000}$$

Equation 36

Explanation of symbols:			
$E_{emptying\_comp}$	Emission per event to air of chemical (component) from emptying the IBC, drum or tanker	[kg event^{-1}]	
P	Pressure of drum/IBC/tanker	[Pa]	Default = 1.01×10^5 Pa
V_s	Volume of substance emptied	[litres unit load^{-1}]	Substance-specific data or Table 0.1.
R	Ideal gas constant	[J K^{-1} mol^{-1}]	8.314
T	Temperature	[K]	Default = 298K
x_{comp}	Mole fraction of chemical (component) in the liquid	[-]	Default = 1 for pure substances. For mixtures, substance-specific data or Equation 2
y_{comp}	Mole fraction of the chemical	[-]	

Explanation of symbols:			
	(component) in the atmosphere of the tank		
VP_{comp}	Vapour pressure of chemical (component) at temperature T	[Pa]	Substance-specific data
MW_{comp}	Molecular weight of chemical (component)	[g mole^{-1}]	Substance-specific data
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	
1,000	Conversion factor between kg and g	[g kg^{-1}]	

Alternative methods for estimating the emissions of petroleum products from this source for cargo ships are given in Chapter 5.2 of USEPA AP-42.

With regards to emptying drums or IBCs, the approach assumes that the drum or IBC is emptied in essentially a controlled manner, with the use of pumps, taps or aspirators. In the case of drums, it is also possible that the drum is emptied by direct pouring. This may have the potential for higher emissions than estimated for volatile substances, as splashing could lead to a higher volume of air being saturated with the vapour. It is not currently possible to take this into account in the emission estimates in a generic way.

Generic scenarios outlined above do not take into account emission control measures that may be routinely used, such as local exhaust ventilation (LEV). Although LEV will be commonplace for many operations involving emptying drums, IBCs or storage tanks as a result of legislation to protect workers, such measures do not necessarily result in reduced emissions to the environment. For example, LEV in its simplest form merely results in the contaminated air within the working environment being transferred to the outdoor environment.

Exceptions to this occur where the LEV also incorporates some treatment measures, for example activated carbon adsorption of vapours or incineration of the vapours. In these cases, a substantial reduction in the emissions compared with generic cases would be expected. It is recommended that, at sites where it is known that the LEV used incorporates such measures, this is taken into account in the estimated emissions from the site. In the absence of actual data on the efficiencies of the system at the site, it could be considered that techniques such as carbon adsorption have an efficiency of 90 per cent and techniques such as incineration have an efficiency of 99 per cent. Therefore, the resulting emissions calculated using the above approaches should be reduced by a factor of 10 and 100 respectively at sites where these measures apply.

Essentially closed systems can be used for emptying various types of storage tank, drums and IBCs. These may be particularly relevant for the handling of highly toxic substances. Emissions from such systems are expected to be near zero.

Possible volatile losses from residual amounts of substance remaining in the tank, drum or IBC are considered in Section 0.

5.5.2 Solids

Similar to the case with vapours (see Section 0), little information is available with which to generate specific emission scenarios for the emptying of solids from various transport and storage systems. Again, a general approach may be to assume that the volume of substance emptied from the tanker/drum/IBC generates an equal volume of air containing dust. Thus, the scenario developed for filling of containers could equally be applied to emptying of containers. This is outlined below.

It is assumed that the air displaced from emptying the tanker/container/bag is filtered, and that the maximum concentration in the filtered air is between 1 and 10 mg/m^3 (see Section 0). In the absence of any other data, a figure of 1 mg/m^3 is assumed for solids with a low dust generation potential (for example, with a particle size of > 40 μm) and a figure of 10 mg/m^3 is assumed for solids with a high dust generation potential.

$$Vol_{air\_disp} = \frac{M_s}{RHO_s} \times D \qquad \text{Equation 37}$$

$$E_{unloading\_dust} = \frac{Vol_{air\_disp} \times Conc_{air}}{1 \times 10^6} \qquad \text{Equation 38}$$

Explanation of symbols:			
$E_{unloading\_dust}$	Emission per event to air from emptying	[kg event^{-1}]	
M_s	Mass of substance emptied from tanker/drum/IBC/bag/silo. This is taken to be equal to the net weight of the vessel for complete emptying of the vessel.[a]	[kg unit load^{-1}]	Table 0.1
Vol_{air_disp}	Volume of air displaced during emptying	[m^3]	
RHO_s	Bulk density of substance[a]	[kg m^{-3}]	Substance-specific information
D	Dispersion factor to take account of the fact that the volume of air displaced may be higher than the volume of substance added	[-]	Suggested default in the range 1-1,000 (see discussion below)
$Conc_{air}$	Concentration of substance in air[b]	[mg m^{-3}]	Substance-specific information or default = 1 mg/m^3 for particle size > 40 μm or 10 mg/m^3 for particle size < 40 μm
1×10^6	Conversion factor between kg and mg	[mg kg^{-1}]	

Note: a) The volume of solid added can be substituted for the term M_s/RHO_s if known.

b) For mixtures/preparations, the concentration of the specific component of interest ($Conc_{air} \times f_{comp}$) should be used, where f_{comp} = weight fraction of the specific component in the preparation or mixture.

As indicated above, these calculations assume some sort of dust filtering system will be present during the emptying operation. Actual emissions in cases where no such system is used may be higher than estimated here, but it is not possible to estimate such emissions directly. As a worse case approach, it could be assumed that the unfiltered emissions are a factor of 10 higher than the filtered emissions (that is, the filtering efficiency is around 90 per cent).

For the emptying of bags and sacks, a specific scenario has been developed already in the ESD on plastics additives (OECD, 2004a) and paint additives (Environment Agency, 2003), and this can be used as an alternative to the above generic emission scenario. The information in OECD (2004a) is discussed in Section 0 and indicates an emission of around 0.5 per cent (five kg per tonne) for particle sizes less than 40 µm and 0.1 per cent (one kg per tonne) for particle sizes greater than 40 µm for situations without any dust collection systems. A similar emission of around 0.5 per cent before any dust collection system is assumed in Environment Agency (2003). These figures again suggest that dispersion factors (*D*) of 1,000 (or even 10,000) may need to be considered for some situations.

Although the major source of emission is likely to be initially dust to the air, particulates would be expected to settle rapidly within the workplace and so could lead to emissions to other phases, such as waste water or solid disposal, as a result of cleaning down of surfaces, floors and so on.

5.5.3 Liquids

There is the potential for loss of liquids from emptying of tankers, drums or IBCs as a result of spills or drips. As discussed in Section 0, current best practice is that such operations are carried out in bunded areas or use some other type of collection and containment system, to minimise the potential for emission to the environment if such drips or spills occur. However, if such measures are not in place then the potential or emissions to the environment exists. It is not currently possible to estimate the magnitude of these emissions, as they are likely to depend on the specific operating practice at the site of interest.

5.6 Emission scenario for storage of liquids

Emissions from storage of liquids in certain types of storage tanks can be estimated using the USEPA TANKS program. Other methods that can be used are summarised below.

The Institute of Petroleum (2000) offers recommended methods for estimating the emissions of volatile substances from breathing losses from petroleum products stored in underground storage tanks at service stations. The method outlined below is adapted from Institute of Petroleum (2000).

Underground storage tanks

$$E_{breathing\_underground\_storage\_air} = 0.33 \times \frac{V_s}{1{,}000} \times \frac{VP_s}{1 \times 10^5}$$ Equation 39

Explanation of symbols:			
$E_{breathing\_undergroud\_storage\_air}$	Emission per day to air from breathing loss from storage	[kg day^{-1}]	
V_s	Volume of substance in tank	[litres tank^{-1}]	Substance-specific data or Table 0.1.
VP_s	Vapour pressure of the substance[a]	[Pa]	Substance-specific data
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	
1×10^5	Conversion factor between Pa and atmosphere	[Pa atm^{-1}]	

Note: a) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

5.7 Generic emission scenario for storage of solids

Storage of solids is likely to take place in piles, silos or as packaged good. Emissions during storage from silos and packaged goods are thought to be minimal (the main sources of emissions in these cases are from filling and emptying). Dust emissions could potentially occur during storage of chemicals in piles (particularly open piles) but the actual emissions depend on a number of site-specific factors such as prevailing winds. It is not possible to generate a generic emission for such losses. Chemicals stored in open piles will usually be minerals and ores rather than refined chemical products.

5.8 Generic emission scenario for pipelines

Emissions from pipelines depend on a number of site-specific factors such as the number of seals and valves in the system, maintenance and inspection regimes and leak detection measures in place, and so are very difficult to estimate in a generic fashion. Emissions from leaks in pipelines are likely to occur mainly to the soil compartment. As pipelines may cover relatively large distances, emissions should be considered as regional or area emissions rather than point source ones. Critical failure of the pipeline is not considered in this ESD.

As a starting point to assess the possible significance of pipelines as a source of emission, the overall known loss rate from pipelines could be considered. This loss rate is estimated at around 0.00035 per cent of the total volume of oil carried in pipelines (see Section 0). Assuming that this rate can be applied to other situations, the following emission scenario can be considered as a starting point.

$$E_{pipeline\_soil} = M_s \times 3.5 \times 10^{-6}$$ Equation 40

Explanation of symbols:			
$E_{pipeline\_soil}$	Emission per day to soil from leakage from pipeline	[kg day^{-1}]	
M_s	Mass of substance piped per day	[kg day^{1}]	Substance-specific data

The above emission factor is based on spillages for one year, and is dominated by one event (see Section 3.5). As such, it has to be considered to be of relatively low reliability. It is therefore recommended that further site-specific information is obtained if the above approach indicates that emissions from this source could be significant.

5.9 Generic emission scenarios for washing and cleaning

This section considers the emissions from washing and cleaning of tankers, drums or IBCs. Such processes generally take place at sites specialised in cleaning such vessels. For drum and IBC washing, the washing water is often re-used in several cleaning cycles, and this has been taken into account in the emission scenarios derived. For tanker cleaning, the cleaning water is rarely re-used.

The basic assumption in these scenarios is that all of the residual substance in the tanker, drum or IBC is removed by the cleaning process.

The scenarios presented in Sections 0 to 0 estimate the emissions to waste water prior to any on-site waste water treatment. On-site waste water treatment is likely to be present at most sites carrying out such cleaning operations, and Section 0 gives methods for estimating the effect of this on the final emission to water from the site.

5.9.1 Road tankers (and other tankers)

Emissions to water from the cleaning process can be estimated using the following equation.

$$E_{road\_tanker\_cleaning\_water} = M_s \times F_{resid} \times N \qquad \text{Equation 41}$$

or

$$E_{road\_tanker\_cleaning\_water} = \frac{V_s \times RHO_s \times F_{resid} \times N}{1{,}000} \qquad \text{Equation 42}$$

Explanation of symbols:			
$E_{road\_tanker\_cleaning\_water}$	Emission per day to water from road tanker cleaning	[kg day^{-1}]	
M_s	Mass of substance in tanker[a] when full	[kg tanker^{-1}]	Substance-specific data or Table 0.1

Explanation of symbols:			
V_s	Volume of substance in tanker when full	[litres tanker^{-1}]	Substance-specific data or Table 0.1.
F_{resid}	Fraction of full load of substance remaining in tanker before cleaning	[-]	Substance-specific data. Default = 0 for highly volatile chemicals 0.01 for viscous liquids 0.002 for other liquids 0.001 for fine powders 0 for other solids
RHO_s	Density of substance	[kg m^{-3}]	Substance-specific data
N	Number of tankers containing the substance cleaned at a site per day	[tankers d^{-1}]	Default = 1
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	

Note: a) For mixtures/preparations mass of substance in the tanker should be taken to be Mcomp (as calculated by Equation 1).

The emissions to water estimated using this approach are before any waste water treatment. Cleaning water from the process may be collected for disposal by a registered waste disposal company (particularly in the case of hazardous substances) or may be released into the waste water stream for on-site treatment before discharge from the cleaning site. Section 0 considers the effect of on-site waste water treatment on the final emissions to water from the site.

As well as emissions to water, emissions to air could also theoretically occur during the washing of tankers (assuming that the vapours in the tanker have not been vented prior to arrival at the cleaning station). In order to estimate these emissions, it could be assumed that vapour within the tanker is saturated with the substance, and this amount of substance is subsequently lost to the atmosphere when the tanker is opened for cleaning. This approach is outlined below and defines the maximum emission likely from this source.

$$E_{road\_tanker\_cleaning\_air} = \frac{VP_s \times V_t \times MW \times N}{Atm. \times MV} \qquad \text{Equation 43}$$

Explanation of symbols:			
$E_{road\_tanker\_cleaning\_air}$	Emission per day to air from road tanker cleaning	[kg day^{-1}]	
V_t	Volume of tanker	[litres tanker^{-1}]	Substance-specific data or Table 0.1. This could be assumed to be the same as the volume of substance initially in the tanker (V_s).
VP_s	Vapour pressure of the substance[a]	[Pa]	Substance-specific data.
MW	Molecular weight of the substance	[g mol^{-1}]	Substance-specific data
$Atm.$	Atmospheric pressure	[Pa]	Default = 101,325 Pa

Explanation of symbols:			
MV	Molar volume of a gas	[litres mole^{-1}]	Default = 22.4 l mole^{-1}
N	Number of tankers containing the substance cleaned at a site per day	[tankers d^{-1}]	Default = 1

Note: a) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

A similar approach to that outlined above could also be used for the cleaning of rail and ship tankers. For ship tankers, regulations limit the maximum permitted residues in the tanks following emptying (see Section 0). For ships constructed on or after the 1st of January 2007, the maximum permitted residue in the tank will be 75 litres for hazardous substances, compared with the current permitted residue of 100 or 300 litres depending on the hazard category of the substance. IMO (2003) should be consulted for the actual requirements related to a specific chemical.

5.9.2 Drums

A similar approach to that outlined above for road tankers can be used to estimate the emissions from drum cleaning. The corresponding equations are outlined below. These methods are only applicable to drum cleaning. For drum burning, emissions of the substance being carried in the drum to water and air are thought to be negligible.

a) Assuming no re-use of the cleaning solution

$$E_{drum\_cleaning\_water} = M_s \times F_{resid} \times N_{site} \times F_{total\_drum} \qquad \text{Equation 44}$$

or

$$E_{drum\_cleaning\_water} = \frac{V_s \times RHO_s \times F_{resid} \times N_{site} \times F_{total\_drum}}{1{,}000} \quad \text{Equation 45}$$

$$E_{drum\_cleaning\_air} = \frac{VP_s \times V_t \times MW \times N_{site} \times F_{total\_drum}}{Atm. \times MV} \qquad \text{Equation 46}$$

Explanation of symbols:			
$E_{drum\_cleaning\_water}$	Emission per day to water from drum cleaning	[kg day^{-1}]	
$E_{drum\_cleaning\_air}$	Emission per day to air from drum cleaning	[kg day^{-1}]	
M_s	Mass of substance in drum[b] when full	[kg drum^{-1}]	Substance-specific data or Table 0.1
V_s	Volume of substance in drum when full	[litres drum^{-1}]	Substance-specific data or Table 0.1. Default = 205 l

Explanation of symbols:			
			$drum^{-1}$.
V_t	Volume of drum	[$litres\ drum^{-1}$]	Substance-specific data or Table 0.1. Default = 205 l $drum^{-1}$.
F_{resid}	Fraction of full load of substance remaining in drum before cleaning	[-]	Substance-specific data. Default[d] = 0 for highly volatile chemicals 0.01 for viscous liquids 0.002 for other liquids 0.001 for fine powders 0 for other solids
RHO_s	Density of substance	[$kg\ m^{-3}$]	Substance-specific data
VP_s	Vapour pressure of the substance[a]	[Pa]	Substance-specific data.
MW	Molecular weight of the substance	[$g\ mol^{-1}$]	Substance-specific data
$Atm.$	Atmospheric pressure	[Pa]	Default = 101,325 Pa
MV	Molar volume of a gas	[$litres\ mole^{-1}$]	Default = 22.4 l $mole^{-1}$
N_{site}	Total number of drums cleaned at a site per day	[$drums\ d^{-1}$]	Default = 1,000[c]
F_{total_drum}	Fraction of drums cleaned that contain the substance (or preparation)	[-]	Equation 11[c]
1,000	Conversion factor between m^3 and litres	[$litres\ m^{-3}$]	

Note: a) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

b) For mixtures/preparations, mass of substance in the tanker should be taken to be Mcomp (as calculated by Equation 1).

c) The term $N_{site} \times F_{total\_drum}$ represents the number of drums containing the specific substance cleaned at the site on any given day. If this term is less than one then a value of one should be used in the calculation in place of this term (that is, one drum containing the substance is cleaned at the site). In all other cases, the nearest whole number should be used.

d) Default value used in North America is 0.03 for all substances.

b) Assuming the cleaning solution is re-used

Where the cleaning solution is re-used, calculations should be modified to account for the fact that only a small fraction of the total solution will be lost during each cleaning cycle, and that concentrations of contaminants could build up within the cleaning solution with increasing number of cycles. In this case, the following equations are relevant. Equation 47 gives the emission on the final day of use of the solution, which will be the highest value. The spent solution may be collected for disposal rather than being discharged to waste water.

$$E_{\text{drum\_cleaning\_water\_reuse}} = \left[E_{drum\_cleaning\_water} + \sum_{x=1}^{x=n-1} E_{drum\_cleaning\_water} \times \left(1 - L_{top\_up}\right)^{x} \right] \times L_{top\_up} \quad \text{Equation 47}$$

$$E_{drum\_cleaning\_disposal} = \left[E_{drum\_cleaning\_water} + \sum_{x=1}^{x=n-1} E_{drum\_cleaning\_water} \times \left(1 - L_{top\_up}\right)^{x} \right] \left(1 - L_{top\_up}\right)$$

Equation 48

Explanation of symbols:			
$E_{drum\_cleaning\_water\_re\text{-}use}$	Emission per day to water from drum cleaning, assuming re-use of cleaning solution	[kg day^{-1}]	
$E_{drum\_cleaning\_disposal}$	Emission per day from disposal of spent cleaning solution	[kg day^{-1}]	
$E_{drum\_cleaning\_water}$	Emission per day to water from drum cleaning, assuming no re-use of cleaning solution	[kg day^{-1}]	Equation 44 or Equation 45
$L_{top\text{-}up}$	Fraction of solution lost each day during cleaning. This is equal to the solution top-up rate.	[-]	Default = 0.05
n	Number of days the solution is used for	[-]	Default = 10

Two key assumptions made in the calculations are the solution top-up rate and the number of days the solution is used. Little information is currently available on these aspects. Default assumptions of 0.05 (five per cent) for the solution top-up rate per day and 10 for the number of days of use of the solution (in other words, the solution is used for two weeks) have been included in the method outlined above. However, these values should be reviewed when more reliable data is available.

5.9.3 IBCs

A similar approach to that outlined above for drums can be used to estimate the emissions from IBCs. The corresponding equations are outlined below.

a) Assuming no re-use of the cleaning solution

$$E_{IBC\_cleaning\_water} = M_s \times F_{resid} \times N_{site} \times F_{total\_IBC} \quad \text{Equation 49}$$

or

$$E_{IBC\_cleaning\_water} = \frac{V_s \times F_{resid} \times N_{site} \times F_{total\_IBC} \times 1{,}000}{RHO_s} \quad \text{Equation 50}$$

$$E_{IBC\_cleaning\_air} = \frac{VP_s \times V_t \times MW \times N_{site} \times F_{total\_IBC}}{Atm. \times MV} \quad \text{Equation 51}$$

Explanation of symbols:			
$E_{IBC\_cleaning\_water}$	Emission per day to water from IBC cleaning	[kg day^{-1}]	
$E_{IBC\_cleaning\_air}$	Emission per day to air from IBC cleaning	[kg day^{-1}]	
M_s	Mass of substance in IBC[b] when full	[kg IBC^{-1}]	Substance-specific data or Table 0.1. Default 1,000 kg IBC^{-1}
V_s	Volume of substance in IBC when full	[litres IBC^{-1}]	Substance-specific data or Table 0.1. Default = 1,250 l IBC^{-1}.
V_t	Volume of IBC	[litres drum^{-1}]	Substance-specific data or Table 0.1. Default = 1,250 l IBC^{-1}.
F_{resid}	Fraction of full load of substance remaining in IBC before cleaning	[-]	Substance-specific data. Default[d] = 0 for highly volatile chemicals 0.01 for viscous liquids 0.003 for other liquids and hazardous substances 0.001 for fine powders 0 for other solids
RHO_s	Density of substance	[kg m^{-3}]	Substance-specific data
VP_s	Vapour pressure of the substance[a]	[Pa]	Substance-specific data.
MW	Molecular weight of the substance	[g mol^{-1}]	Substance-specific data
$Atm.$	Atmospheric pressure	[Pa]	Default = 101,325 Pa
MV	Molar volume of a gas	[litres mole^{-1}]	Default = 22.4 l mole^{-1}
N_{site}	Total number of IBCs cleaned at a site per day	[drums d^{-1}]	Default = 100[c]
F_{total_IBC}	Fraction of IBCs cleaned that contain the substance (or preparation)	[-]	Equation 11[c]
1,000	Conversion factor between m^3 and litres	[litres m^{-3}]	

Note: a) For mixtures/preparations, the partial vapour pressure of the specific component of interest (P_{comp}) should be used. This can be estimated from Equation 4.

b) For mixtures/preparations, mass of substance in the IBC should be taken to be Mcomp (as calculated by Equation 1).

c) The term $N_{site} \times F_{total\_IBC}$ represents the number of IBCs containing the specific substance cleaned at the site on any given day. If this term is less than one then a value of one should be used in the calculation in

place of this term (that is, one IBC containing the substance is cleaned at the site). In all other cases the nearest whole number should be used.
d) Default value for US is 0.005 and for Canada is 0.002, for all substances in both countries.

b) Assuming the cleaning solution is re-used

Where the cleaning solution is re-used, calculations should be modified to account for the fact that only a small fraction of the total solution will be lost during each cleaning cycle, and that concentrations of contaminants could build up within the cleaning solution with increasing number of cycles. In this case, the following equations are relevant. Equation 52 gives the emission on the final day of use of the solution, which will be the highest value. The spent solution may be collected for disposal rather than being discharged to waste water.

$$E_{IBC\_cleaning\_water\_reuse} = \left[E_{IBC\_cleaning\_water} + \sum_{x=1}^{x=n-1} E_{IBC\_cleaning\_water} \times \left(1 - L_{top\_up}\right)^{x} \right] \times L_{top\_up}$$

Equation 52

$$E_{IBC\_cleaning\_disposal} = \left[E_{IBC\_cleaning\_water} + \sum_{x=1}^{x=n-1} E_{IBC\_cleaning\_water} \times \left(1 - L_{top\_up}\right)^{x} \right] \left(1 - L_{top\_up}\right)$$

Equation 53

Explanation of symbols:			
$E_{IBC\_cleaning\_water}$	Emission per day to water from IBC cleaning, assuming re-use of cleaning solution	[kg day^{-1}]	
$E_{IBC\_cleaning\_disposal}$	Emission per day from disposal of spent cleaning solution	[kg day^{-1}]	
$E_{IBC\_cleaning\_water}$	Emission per day to water from IBC cleaning, assuming no re-use of cleaning solution	[kg day^{-1}]	Equation 49 or Equation 50
$L_{top\text{-}up}$	Fraction of solution lost each day during cleaning. This is equal to the solution top-up rate.	[-]	Default = 0.05
n	Number of days the solution is used for	[-]	Default = 10

Two key assumptions made in the calculations are the solution top-up rate and the number of days the solution is used. No information is currently available on these two aspects. Similar to the case with drums, default assumptions of 0.05 (five per cent) for the daily solution top-up rate and 10 for the number of days of use of the solution have been included in the method outlined above. However, these values should be reviewed when more reliable data is available.

5.9.4 Storage tanks

The cleaning of storage tanks is generally carried out on site by specialist waste companies. The cleaning company would normally take away the washings for disposal. It is therefore not possible to derive a generic emission scenario for this aspect.

5.9.5 Consideration of waste water treatment at washing and cleaning sites

The emissions calculated in Sections 0 to 0 are all emissions to waste water before any on-site waste water treatment measures are undertaken. The on-site waste water treatment measures can range from no on-site treatment, to primary treatment such as oil separation, to biological waste water treatment to collection of the waste water for suitable disposal off-site. The level of treatment reflects the hazardous nature of the products cleaned; for example, waste water from the cleaning of highly hazardous products is most likely to be collected for suitable disposal rather than being discharged directly to sewer. In the case of oil-water separation, once the oil phase has been collected and removed it either undergoes further treatment or is recycled. Storage facilities are necessary for skimmed oil and sludge if the oil cannot be recycled immediately. If skimmed oil is not re-used after minor cleaning operations, it is chemical waste and has to be disposed of adequately, together with separated solids (European Commission, 2005).

Oil-water separation is not usually a stand-alone process, but is followed by flotation supported by coagulation/flocculation (European Commission, 2005). The three commonly used oil-water separators, in order of increasing efficiency, are the American Petroleum Institute separator (API), the parallel plate interceptor (PPI) and the corrugated plate interceptor (CPI). API separators are also used to protect downstream equipment from large oil slugs originating from an operational failure, whereas PPI and CPI are more efficient at removing smaller oil droplets. Oil-water separators are estimated to remove 90 to 95 per cent of oil and solids.

The effect of various treatment measures on resulting emissions can be estimated using the following approaches.

For waste water that is collected for suitable disposal off-site (such as incineration or landfill), a zero emission from the cleaning site can be assumed.

For sites with an on-site waste water treatment plant, the degree of removal of the substance during treatment can be estimated using the waste water treatment plant model within the TGD (European Commission, 2003c).

For primary treatment, it is much more difficult to predict the effect that this will have on the final emissions to sewer as this depends on a number of factors, including the water solubility of the substance emitted and the amount of insoluble oils emitted from the site. An approach to estimating this removal is given below. The approach is based on methods outlined in OECD (2004b) and assumes the partitioning of a substance between water and an insoluble oil phase is instantaneous and can be modelled using the log Kow (that is, the properties of the oil phase are similar to n-octanol).

The approach assumes that the maximum amount of oil present after primary treatment with a Class 1 separator is around 5 ppm (5 mg/l); this is generally regarded as the maximum acceptable level by most local authorities since at this level the residual oil becomes visible as a contaminant. However, Class 2 separators are designed to achieve a concentration of less than 100 mg/l oil under standard conditions (Environment Agency, 2004d). This class of separator is suitable for dealing with discharges where a lower quality requirement applies, for example where effluent passes for foul sewer (and so is subsequently treated in a further waste water treatment plant), and for trapping spillages.

Using the octanol-water partition coefficient of the chemical Kow as a measure of the partitioning between the oil and water, the following equation can be derived.

$$Kow = \frac{C_{oil}}{C_{water}} = \frac{Q_{s\_oil} / V_{oil}}{Q_{s\_water} / V_{water}} \qquad \text{Equation 54}$$

From mass balance the following must also hold.

$$Q_{s\_oil} + Q_{s\_water} = E_{water} \qquad \text{Equation 55}$$

Rearranging these equations gives the following two equations.

$$Q_{s\_oil} = \frac{V_{oil} \times Kow}{V_{water}} \times Q_{s\_water} \qquad \text{Equation 56}$$

$$Q_{s\_oil} = E_{water} - Q_{s\_water} \qquad \text{Equation 57}$$

Combining these two equations gives the amount of substance dissolved in the water phase after primary treatment (Q_{s_water}).

$$\frac{V_{oil} \times Kow}{V_{water}} \times Q_{s\_water} = E_{water} - Q_{s\_water} \qquad \text{Equation 58}$$

$$Q_{s\_water} = \frac{E_{water}}{\left(1 + \frac{V_{oil}}{V_{water}} \times Kow\right)} \qquad \text{Equation 59}$$

In addition, water after primary treatment may contain up to 5 mg/l (5×10^{-6} kg/l) or 100 mg/l (i.e. 1×10^{-4} kg/l) of oil depending on the type of separator, Class 1 or 2, respectively. The mass of the substance in the total oil volume discharge per day is given by Q_{s_oil} in the above equations.

The fraction of this oil released depends on the water volume.

Class 1 Separator (where, for example, drainage passes to surface water sewer)

$$5 \times 10^{-6} = \frac{F_{oil} \times \frac{V_{oil} \times 1{,}000}{RHO_{oil}}}{V_{water}} \qquad \text{Equation 60}$$

Class 2 Separator (where, for example, effluent passes to foul sewer)

$$1 \times 10^{-4} = \frac{F_{oil} \times \frac{V_{oil} \times 1{,}000}{RHO_{oil}}}{V_{water}} \qquad \text{Equation 61}$$

Hence the fraction of oil remaining in the water after primary treatment can be estimated.

Class 1 Separator (where, for example, drainage passes to surface water sewer)

$$F_{oil} = \frac{5 \times 10^{-6} \times V_{water} \times RHO_{oil}}{V_{oil} \times 1{,}000} \qquad \text{Equation 62}$$

Class 2 Separator (where, for example, effluent passes to the foul sewer)

$$F_{oil} = \frac{1 \times 10^{-4} \times V_{water} \times RHO_{oil}}{V_{oil} \times 1{,}000} \qquad \text{Equation 63}$$

Therefore, the total emission to sewer of the substance in question after primary treatment can be estimated using the following equation.

$$E_{sewer} = Q_{s\_water} + F_{oil} \times Q_{s\_oil} \qquad \text{Equation 64}$$

The quantities V_{water} and V_{oil} can be estimated using the following approach.

$$V_{water} = N_{site} \times Water \qquad \text{Equation 65}$$

$$V_{oil} = N_{site} \times F_{water} \times V_{drum/IBC/tanker} \qquad \text{Equation 66}$$

This latter equation effectively assumes that the majority of containers washed at the station contain substances that are ‘oil-like’.

Explanation of symbols:			
E_{sewer}	Emission per day to sewer from cleaning following on-site treatment	[kg day^{-1}]	
E_{water}	Emission per day to waste water from cleaning	[kg day^{-1}]	Sections 0 to 0
K_{ow}	Octanol-water partition coefficient	[-]	Substance-specific information
C_{oil}	Concentration in oil	[kg litre^{-1}]	Not needed
C_{water}	Concentration in water	[kg litre^{-1}]	Not needed
Q_{s_oil}	Quantity of substance in oil in equilibrium with water phase	[kg day^{-1}]	
Q_{s_water}	Quantity of substance in water in equilibrium with oil phase	[kg day^{-1}]	
V_{oil}	Volume of oil in waste water from site (before treatment)	[litres day^{-1}]	
V_{water}	Volume of waste water emitted from site	[litres day^{-1}]	
$V_{drum/IBC/tanker}$	Volume of drum, IBC or tanker	[litres unit^{-1}]	Default = 25,000 for road tankers, 205 for drums or 1,000 for IBCs
RHO_{oil}	Density of oil phase	[kg m^{3}]	Default = 900
F_{oil}	Fraction of oil in waste water emitted to sewer after primary treatment	[-]	
N_{site}	Total number of tankers, drums or IBCs cleaned at the site	[units day^{-1}]	Default = 40 road tankers, 1,000 drums or 100 IBCs
$Water$	Total water consumption per drum or IBC	[litres unit^{-1}]	Default = 2,000 litres for road tankers (see 0) 30 litres for drums (see Section 0) or 250 litres for IBCs (see Section 0)
F_{water}	Fraction of 'oil' released in water from the cleaning process	[-]	Default = 0.01 for viscous liquids
1,000	Conversion factor between m^{3} and litres	[litres m^{-3}]	

For other types of treatment, the final emission to sewer can be estimated using the following equation.

$$E_{sewer} = E_{water} \times F_{treatment\_water}$$ Equation 67

Explanation of symbols:			
E_{sewer}	Emission per day to sewer from cleaning following on-site treatment	[kg day^{-1}]	

Explanation of symbols:			
E_{water}	Emission per day to water from cleaning	[kg day^{-1}]	Sections 0 to 0
$F_{treatment\_water}$	Fraction to effluent during on-site treatment	[-]	Site specific information Default = 0 for collection and treatment off-site. Use TGD method for biological treatment plant.

5.10 Generic emission scenarios for recycling

It is not currently possible to generate generic emissions scenarios for the recycling of drums and IBCs. Recycling of metal and plastic containers is not thought to lead to significant exposure of chemicals previously carried in the containers. Recycling of paper bags could potentially lead to exposure at the paper recycling site, but there is insufficient information available to construct an emission scenario.

5.11 Generic emission scenarios for disposal

The main sources of disposal for packaging are likely to be via landfill or incineration. Incineration is likely to completely destroy any chemicals remaining in the packaging. For landfill disposal, the residual amount of chemical present in the packaging has the potential to be lost from the landfill in leachate or by volatilisation, or may undergo degradation. The actual behaviour in a landfill is a chemical-specific property and is beyond the scope of this ESD. Information on the residual amounts of chemical in packaging that may be disposed of to landfills is discussed in Section 0.

Industrial packaging containing certain amounts of hazardous substances is considered to be special or hazardous waste in the United Kingdom and will be disposed of appropriately (see Section 0).

5.12 Estimation of regional or country-wide emissions

The equations outlined in the previous sections all effectively calculate the emissions that may occur from a local site using a given mass (M_S) or volume (V_S) of a substance. The same methods can be used to estimate emissions from a larger region or a country by simply substituting the total regional mass or volume of the substance for the local mass of volume.

In cases where more than one form of transport, packaging or storage may be used, the regional or country-wide emissions should take into account the relative proportion of the substance carried or stored in the various types of transport or packaging. Where this information is not available, it is recommended that a range for the emissions is estimated by assuming the all of the regional tonnage or volume is carried or stored by each relevant mode of transport or storage in turn.

Regional or country-wide emissions should also consider aggregated releases from all operations carried out over the lifecycle of the chemical, such as losses from filling, emptying, storage and cleaning of the relevant transport and storage systems.

5.13 Example calculations

5.13.1 Example 1 – drum cleaning

A viscous substance used in 1,000 tonnes/year (1×10^6 kg/year) in the United Kingdom. Transported solely in drums. The main physico-chemical properties of the substance are a density of 1,000 kg/m^3 and a log Kow of 4 (Kow = 10,000).

The total number of 205 litre drums containing the substance is estimated using Equation 9.

$$N_{s\_drum} = \frac{Q_{total\_reg} \times 1{,}000}{RHO_s \times V_{drum}} = \frac{V_{total\_reg}}{V_{drum}} \qquad \text{Equation 9}$$

N_{s_drum}	Number of drums containing the substance (or preparation) used in a region/country		
Q_{total_reg}	Total amount of substance (or preparation) produced or used in a region/country	1×10^6 kg year^{-1}	Substance data
V_{drum}	Volume of drum used	205 litres	Default (Section 2.3)
RHO_s	Density of substance (or preparation)	1,000 kg m^{-3}	Substance data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$N_{s\_drum} = 1\times10^6 \times 1{,}000/(1{,}000 \times 205) = 4{,}900$.

The fraction of the total drums cleaned is estimated using Equation 11.

$$F_{total\_drum} = \frac{N_{s\_drum}}{N_{total\_drum}} \qquad \text{Equation 11}$$

F_{total_drum}	Fraction of total drums reconditioned that contain the substance (or preparation)		
N_{s_drum}	Number of drums containing the substance (or preparation) used in a region/country	4,900	From above
N_{total_drum}	Total number of drums reconditioned in a region/country	4,800,000	Default (Section 5.2)

F_{total_drum} = 4,900/4,800,000 = 1×10^{-3}.

The emission to waste water from drum cleaning is estimated from Equations 45 and 47.

Assuming no re-use of cleaning solution

$$E_{drum\_cleaning\_water} = \frac{V_s \times RHO_s \times F_{resid} \times N_{site} \times F_{total\_drum}}{1{,}000} \qquad \text{Equation 45}$$

$E_{drum\_cleaning\_water}$	Emission per day to water from drum cleaning	kg day^{-1}	
V_s	Volume of substance in drum	205 litres	Default (Section 2.3)
F_{resid}	Fraction of full load of substance remaining in IBC before cleaning	0.01	Default for viscous liquids (Section 5.9.2)
RHO_s	Density of substance	1,000 kg m^{-3}	Substance data
N_{site}	Total number of drums cleaned at a site per day	1,000 drums d^{-1}	Default
F_{total_drum}	Fraction of drums cleaned that contain the substance (or preparation)	1×10^{-3}	From above
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$E_{drum\_cleaning\_water}$ = (205 × 1,000 × 0.01 × 1,000 × 1×10^{-3})/1,000 = 2.1 kg/day.

Assuming re-use of cleaning solution Equation 47

$$E_{drum\_cleaning\_water\_reuse} = \left[E_{drum\_cleaning\_water} + \sum_{x=1}^{x=n-1} E_{drum\_cleaning\_water} \times \left(1 - L_{top\_up}\right)^x\right] \times L_{top\_up}$$

$E_{drum\_cleaning\_water\_re\text{-}use}$	Emission per day to water from drum cleaning, assuming re-use of cleaning solution	kg day^{-1}	
$E_{drum\_cleaning\_water}$	Emission per day to water from drum cleaning, assuming no re-use of cleaning solution	2.1 kg day^{-1}	From above
$L_{top\text{-}up}$	Fraction of solution lost each day during cleaning. This is equal to the solution top-up rate.	0.05	Default
n	Number of days the solution is used for	10	Default

$E_{drum\_cleaning\_water\_re\text{-}use} = [2.1 + {}_{x=1}\Sigma^{x=9}(2.1 \times (1\text{-}0.05)^x)] \times 0.05 = 0.84$ kg/day.

This is the release on the final (tenth) day of use of the solution.

Assuming the site has primary waste water treatment, the emission to sewer can be estimated as follows.

$$V_{water} = N_{site} \times Water \qquad \text{Equation 65}$$

V_{water}	Volume of waste water emitted from site	litres day^{-1}	
N_{site}	Total number of drums cleaned at the site	1,000 drums day^{-1}	Default
$Water$	Total water consumption per drum	30 litres $drum^{-1}$	Default (Section 3.6.4)

$V_{water} = 1{,}000 \times 30 = 30{,}000$ litres/day.

$$V_{oil} = N_{site} \times F_{water} \times V_{drum/IBC/tanker} \qquad \text{Equation 66}$$

V_{oil}	Volume of oil in waste water from site (before treatment)	litres day^{-1}	
N_{site}	Total number of drums cleaned at the site	1,000 drums day^{-1}	Default
F_{water}	Fraction of 'oil' released in water from the cleaning process	0.01	Default for viscous liquids (Section 5.9.5)
$V_{drum/IBC/tanker}$	Volume of drum, IBC or tanker	205 litres	Default (Section 2.3)

$V_{oil} = 1{,}000 \times 0.01 \times 205 = 2{,}050$ litres/day.

$$Q_{s\_water} = \frac{E_{water}}{\left(1 + \frac{V_{oil}}{V_{water}} \times Kow\right)} \qquad \text{Equation 59}$$

Q_{s_water}	Quantity of substance in water in equilibrium with oil phase	kg day^{-1}	
E_{water}	Emission per day to waste water from cleaning	0.84 kg day^{-1}	From above, assuming re-use of cleaning solution
V_{oil}	Volume of oil in waste water from site (before treatment)	2,050 litres day^{-1}	From above
V_{water}	Volume of waste water emitted from site	30,000 litres day^{-1}	From above
Kow	Octanol-water partition coefficient	10,000	Substance data

Q_{s_water} = 0.84/[1 + (2,050/30,000) × 10,000] = 0.0012 kg/day.

$$F_{oil} = \frac{5 \times 10^{-6} \times V_{water} \times RHO_{oil}}{V_{oil} \times 1{,}000}$$ Equation 62

F_{oil}	Fraction of oil in waste water emitted to sewer after primary treatment		
RHO_{oil}	Density of oil phase	900 kg m^3	Default (Section 5.9.5)
$V_{oil,}$ V_{water}			From above
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$F_{oil} = 5\times10^{-6} \times 30{,}000 \times 900/(2{,}050 \times 1{,}000) = 6.6\times10^{-5}$.

$$Q_{s\_oil} = E_{water} - Q_{s\_water}$$ Equation 57

Q_{s_oil}	Quantity of substance in oil in equilibrium with water phase	kg day^{-1}	
E_{water}	Emission per day to waste water from cleaning	0.84 kg day^{-1}	From above, assuming re-use of cleaning solution
Q_{s_water}	Quantity of substance in water in equilibrium with oil phase	0.0012 kg day^{-1}	From above

Q_{s_oil} = 1 – 0.0011 = 0.9988 kg/day.

$$E_{sewer} = Q_{s\_water} + F_{oil} \times Q_{s\_oil}$$ Equation 64

E_{sewer}	Emission per day to sewer from cleaning following on-site treatment	kg day^{-1}	

Q_{s_water}	Quantity of substance in water in equilibrium with oil phase	0.0012 kg day^{-1}	From above
F_{oil}	Fraction of oil in waste water emitted to sewer after primary treatment	6.6×10^{-5}	From above
Q_{s_oil}	Quantity of substance in oil in equilibrium with water phase	0.9988 kg day^{-1}	From above

$E_{sewer} = 0.0012 + (0.9988 \times 6.6\times10^{-5}) = 0.0013$ kg/day.

5.13.2 Example 2 – breathing loss from liquid storage

The liquid has a vapour pressure of 10 Pa at 20°C and is stored in an underground storage tank. The volume of the substance in the tank is 10,000 litres.
Using Equation 39:

$$E_{breathing\_underground\_storage\_air} = 0.33 \times \frac{V_s}{1{,}000} \times \frac{VP_s}{1\times10^5} \qquad \text{Equation 39}$$

$E_{breathing\_undergroud\_storage\_air}$	Emission per day to air from breathing loss from storage	kg day^{-1}	
V_s	Volume of substance in tank	10,000 litres	Substance data
VP_s	Vapour pressure of the substance	10 Pa	Substance data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	
	Conversion factor between Pa and atmosphere	1×10^5 Pa atm^{-1}	

$E_{breathing\_underground\_storage\_air} = 0.33 \times(10{,}000/1{,}000) \times (10/1\times10^5) = 3.3\times10^{-4}$ kg/day.

5.13.3 Example 3 – dust emissions from filling an IBC

The substance is a fine powder with a particle size of < 40 µm and has a high potential for dust generation. Using Equations 34 and 35, the following emission can be estimated from each filling event, assuming an IBC size of 1 m^3 and a maximum concentration in the filtered air of 10 mg/m^3.

$$Vol_{air\_disp} = \frac{M_s}{RHO_s} \times D \qquad \text{Equation 34}$$

$$E_{loading\_dust} = \frac{Vol_{air\_disp} \times Conc_{air}}{1\times10^6} \qquad \text{Equation 35}$$

$E_{loading\_dust}$	Emission per event to air of from filling	kg event^{-1}

Vol_{air_disp}	Volume of air displaced during filling of tanker		Calculate from equation 34
D	Dispersion factor to take account of the fact that the volume of air displaced may be higher than the volume of substance added	1,000	Suggested default in the range 1-10,000 (Section 5.4.2)
$Conc_{air}$	Concentration of substance in air	10 mg m^{-3}	Default for particle size <40 µm (Section 5.4.2)
	Conversion factor between kg and mg	1×10^{6} mg kg^{-1}	

For this example, the volume of the IBC is given as 1 m^3, equivalent to M_s/RHO_s

$Vol_{air\_disp} = 1 \times 1{,}000 = 1{,}000\ m^3$ per event.

$E_{loading\_dust} = 1{,}000 \times 10/1\times10^6 = 0.01$ kg per event.

Assuming 10 IBCs are loaded per day, this gives a total emission of 0.1 kg/day as dust.

5.13.4 Example 4 – vapour emissions from drum emptying

The substance is a pure substance with a vapour pressure of 200 Pa at 25°C and has a molecular weight of 70 g/mole. The 205 litre drum is emptied at an ambient temperature of 25°C. Using Equation 36 the following emission can be estimated.

$$E_{emptying\_comp} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1{,}000} \qquad \text{Equation 36}$$

$E_{emptying\_comp}$	Emission per event to air of chemical (component) from emptying the drum	kg event^{-1}	
V_s	Volume of substance emptied	205 litres	Substance data
R	Ideal gas constant	8.314 J K^{-1} mol^{-1}	
T	Temperature	298 K	Default
x_{comp}	Mole fraction of chemical (component) in the liquid	1	Default for pure substances
VP_{comp}	Vapour pressure of chemical (component) at temperature T	200 Pa	Substance-specific data
MW_{comp}	Molecular weight of chemical (component)	70 g mole^{-1}	Substance-specific data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	
	Conversion factor between kg and g	1,000 g kg^{-1}	

$E_{emptying}$ = 205 × 1 × 200 × 70/(8.314 × 298 × 1,000 × 1,000) = 1.2×10^{-3} kg/event.

Assuming 10 drums are emptied per day, the total daily emission of vapour would be 0.012 kg/day.

5.13.5 Example 5 – drum filling, emptying and cleaning

A liquid produced in the United Kingdom at 2,000 tonnes/year (2×10^{6} kg/year) and is transported solely in drums. The main physico-chemical properties of the substance are a density of 1,000 kg/m^3 and a log Kow of 4 (Kow = 10,000). The substance has a purity of more than 99 per cent, molecular weight 250 g/mole and vapour pressure at 25°C is 75 Pa. The 205 litre drum is filled at ambient temperature of 25°C and all the drums are filled at the production site. Using Equation 33 the following emission can be estimated.

$$E_{drum\_filling\_comp} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1{,}000} \qquad \text{Equation 33}$$

$E_{drum\_filling\_comp}$	Emission per event to air of chemical (component) from filling the drum	kg event^{-1}	
V_s	Volume of substance emptied	205 litres	Substance data
R	Ideal gas constant	8.314 J K^{-1} mol^{-1}	
T	Temperature	298 K	Default
x_{comp}	Mole fraction of chemical (component) in the liquid	1	Default for pure substances
VP_{comp}	Vapour pressure of chemical (component) at temperature T	75 Pa	Substance-specific data
MW_{comp}	Molecular weight of chemical (component)	250 g mole^{-1}	Substance-specific data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	
	Conversion factor between kg and g	1,000 g kg^{-1}	

$E_{drum\_filling\_comp}$ = 205 × 1 × 75 × 250/(8.314 × 298 × 1,000 × 1,000) = 1.5×10^{-3} kg/event.

The total number of 205 litre drums containing the substance is estimated using Equation 9.

$$N_{s\_drum} = \frac{Q_{total\_reg} \times 1{,}000}{RHO_s \times V_{drum}} = \frac{V_{total\_reg}}{V_{drum}} \qquad \text{Equation 9}$$

N_{s_drum}	Number of drums containing the substance (or preparation) used in a region/country		
Q_{total_reg}	Total amount of substance (or preparation) produced or used in a region/country	$2\text{x}10^{6}$ kg year^{-1}	Substance data

V_{drum}	Volume of drum used	205 litres	Default (Section 2.3)
RHO_s	Density of substance (or preparation)	1,000 kg m^{-3}	Substance data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$N_{s\_drum} = 2\times10^6 \times 1{,}000/(1{,}000 \times 205) = 9{,}756$.

Thus, the total emission from the production site = 9,756×1.5×10^{-3} = 14.6 kg/year or 0.05 kg/day assuming 300 working days per year.

Equation 36 can be used to estimate the following emission when the drum is emptied. The drums are emptied at downstream user sites.

$$E_{emptying\_comp} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1{,}000} \qquad \text{Equation 36}$$

$E_{emptying\_comp}$	Emission per event to air of chemical (component) from emptying the drum	kg event^{-1}	
V_s	Volume of substance emptied	205 litres	Substance data
R	Ideal gas constant	8.314 J K^{-1} mol^{-1}	
T	Temperature	298 K	Default
x_{comp}	Mole fraction of chemical (component) in the liquid	1	Default for pure substances
VP_{comp}	Vapour pressure of chemical (component) at temperature T	75 Pa	Substance-specific data
MW_{comp}	Molecular weight of chemical (component)	250 g mole^{-1}	Substance-specific data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	
	Conversion factor between kg and g	1,000 g kg^{-1}	

$E_{emptying} = 205 \times 1 \times 75 \times 250/(8.314 \times 298 \times 1{,}000 \times 1{,}000) = 1.6\times10^{-3}$ kg/event.

Assuming 10 drums per day are emptied at a site, then the total emission from the site would be 0.016 kg/day.

On a country-wide basis, the total daily emission of vapour from emptying these drums would be 0.05 kg/day [(9,756/300) × 1.6×10^{-3} kg/event]. This calculation is based on 300 working days per year.

Once emptied, the drums are all sent for cleaning. Approximately 4,800,000 drums are reconditioned in the United Kingdom every year. The fraction of the total drums cleaned that contain the substance is estimated using Equation 11.

$$F_{total\_drum} = \frac{N_{s\_drum}}{N_{total\_drum}} \qquad \text{Equation 11}$$

F_{total_drum}	Fraction of total drums reconditioned that contain the substance (or preparation)		
N_{s_drum}	Number of drums containing the substance (or preparation) used in a region/country	9,756	From above
N_{total_drum}	Total number of drums reconditioned in a region/country	4,800,000	Default (Section 5.2)

$F_{total\_drum} = 9{,}756/4{,}800{,}000 = 2\times10^{-3}$.

The emission to waste water from a drum cleaning site is estimated from Equations 45 and 47. The fraction of substance released in water from the cleaning process is 0.002 for liquids.

Assuming no re-use of cleaning solution

$$E_{drum\_cleaning\_water} = \frac{V_s \times RHO_s \times F_{resid} \times N_{site} \times F_{total\_drum}}{1{,}000} \qquad \text{Equation 45}$$

$E_{drum\_cleaning\_water}$	Emission per day to water from drum cleaning	kg day^{-1}	
V_s	Volume of substance in drum	205 litres $drum^{-1}$	Default (Section 2.3)
F_{resid}	Fraction of full load of substance remaining in IBC before cleaning	0.002	Default for liquids (Section 5.9.2)
RHO_s	Density of substance	1,000 kg m^{-3}	Substance data
N_{site}	Total number of drums cleaned at a site per day	1,000 drums d^{-1}	Default
F_{total_drum}	Fraction of drums cleaned that contain the substance (or preparation)	2×10^{-3}	From above
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$E_{drum\_cleaning\_water} = 205 \times 0.002 \times 1{,}000 \times 2\times10^{-3} = 0.8$ kg/day.

Assuming re-use of cleaning solution

$$E_{\mathrm{drum\_cleaning\_water\_reuse}} = \left[E_{drum\_cleaning\_water} + \sum_{x=1}^{x=n-1} E_{drum\_cleaning\_water} \times \left(1 - L_{top\_up}\right)^{x} \right] \times L_{top\_up}$$

Equation 47

$E_{drum\_cleaning\_water\_re\text{-}use}$	Emission per day to water from drum cleaning, assuming re-use of cleaning solution	kg day^{-1}	
$E_{drum\_cleaning\_water}$	Emission per day to water from drum cleaning, assuming no re-use of cleaning solution	0.8 kg day^{-1}	From above
$L_{top\text{-}up}$	Fraction of solution lost each day during cleaning. This is equal to the solution top up rate.	0.05	Default
n	Number of days the solution is used for	10	Default

$E_{drum\_cleaning\_water\_re\text{-}use} = [0.8 + {}_{x=1}\Sigma^{x=9}(0.8 \times (1-0.05)^{x})] \times 0.05 = 0.32$ kg/day.

This is the emission on the last (tenth) day of use of the solution.

The spent solution may be collected for disposal rather than being discharged to waste water, and this emission can be estimated using Equation 48.

$$E_{drum\_cleaning\_disposal} = \left[E_{drum\_cleaning\_water} + \sum_{x=1}^{x=n-1} E_{drum\_cleaning\_water} \times \left(1 - L_{top\_up}\right)^{x} \right] \left(1 - L_{top\_up}\right)$$

Equation 48

$E_{drum\_cleaning\_water\_disposal} = [0.8 + {}_{x=1}\Sigma^{x=9}(0.8 \times (1-0.05)^{x})]\ (1-0.05) = 6.1$ kg/day.

Assuming the site has primary waste water treatment, the emission to sewer can be estimated using Equations 59 - 64. A Class 1 separator is used, and the maximum amount of oil that would be present in oil after the primary treatment is around 5 ppm (5 mg/l).

$$V_{water} = N_{site} \times Water \qquad \text{Equation 65}$$

V_{water}	Volume of waste water emitted from site	litres day^{-1}	
N_{site}	Total number of drums cleaned at the site	1,000 drums day^{-1}	Default (Section 5.9.2)
$Water$	Total water consumption per drum	30 litres $drum^{-1}$	Default (Section 3.6.4)

$V_{water} = 1{,}000 \times 30 = 30{,}000$ litres/day.

$$V_{oil} = N_{site} \times F_{water} \times V_{drum/IBC/tanker}$$ Equation 66

V_{oil}	Volume of oil in waste water from site (before treatment)	litres day^{-1}	
N_{site}	Total number of drums cleaned at the site	1,000 drums day^{-1}	Default (Section 5.9.2)
F_{water}	Fraction of 'oil' released in water from the cleaning process	0.002	Default for liquids (Section 5.9.5)
$V_{drum/IBC/tanker}$	Volume of drum, IBC or tanker	205 litres	Default (Section 2.3)

V_{oil} = 1,000 × 0.002 × 205 = 410 litres/day.

$$Q_{s\_water} = \frac{E_{water}}{\left(1 + \frac{V_{oil}}{V_{water}} \times Kow\right)}$$ Equation 59

Q_{s_water}	Quantity of substance in water in equilibrium with oil phase	kg day^{-1}	
E_{water} (in this case $E_{drum\_cleaning\_water\_re\text{-}use}$)	Emission per day to waste water from cleaning	0.32 kg day^{-1}	From above, assuming re-use of cleaning solution
V_{oil}	Volume of oil in waste water from site (before treatment)	410 litres day^{-1}	From above
V_{water}	Volume of waste water emitted from site	30,000 litres day^{-1}	From above
Kow	Octanol-water partition coefficient	10,000	Substance data

Q_{s_water} = 0.32/[1 + ((410/30,000) × 10,000)] = 0.0023 kg/day.

$$F_{oil} = \frac{5 \times 10^{-6} \times V_{water} \times RHO_{oil}}{V_{oil} \times 1{,}000}$$ Equation 62

F_{oil}	Fraction of oil in waste water emitted to sewer after primary treatment		
RHO_{oil}	Density of oil phase	900 kg m^{3}	Default (Section 5.9.5)
V_{oil}, V_{water}			From above
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

F_{oil} = 5×10^{-6} × 30,000 × 900/(410 × 1,000) = 3.3×10^{-4}.

$$Q_{s\_oil} = E_{water} - Q_{s\_water}$$ Equation 57

Q_{s_oil}	Quantity of substance in oil in equilibrium with water phase	kg day^{-1}	
E_{water}	Emission per day to waste water from cleaning	0.32 kg day^{-1}	From above
Q_{s_water}	Quantity of substance in water in equilibrium with oil phase	0.0023 kg day^{-1}	From above

$Q_{s\text{-}oil}$ = 0.32 – 0.0023 = 0.3177 kg/day.

$$E_{sewer} = Q_{s\_water} + F_{oil} \times Q_{s\_oil} \qquad \text{Equation 64}$$

E_{sewer}	Emission per day to sewer from cleaning following on-site treatment	kg day^{-1}	
Q_{s_water}	Quantity of substance in water in equilibrium with oil phase	0.0023 kg day^{-1}	From above
$F_{\_oil}$	Fraction of oil in waste water emitted to sewer after primary treatment	3.3×10^{-4}	From above
Q_{s_oil}	Quantity of substance in oil in equilibrium with water phase	0.3177 kg day^{-1}	From above

E_{sewer} = 0.0023 + (0.3177 × 3.3×10^{-4}) = 0.0024 kg/day.

The total country-wide emission to waste water (before waste water treatment) from drum cleaning can be estimated from Equations 45 and 47, by substituting the total number of drums containing the substance (9,756) into the equations to represent the total number of drums cleaned (in other words, to replace the term $N_{site} \times F_{total\_drum}$). This gives a total country-wide emission of 3,900 kg/year assuming no re-use of cleaning water, or 1,560 kg/year assuming water is re-used.

5.13.6 Example 6 – IBC filling and emptying

The substance is a fine powder with a particle size of < 40 µm and has a high potential for dust generation. One thousand tonnes of this pure substance are produced each year (1×10^6 kg/year) in the United Kingdom and the maximum concentration in the filtered air during filling/emptying operations is 10 mg/m^3. The main physico-chemical properties of the substance are a density of 1,000 kg/m^3, a log Kow of 3.75 (Kow = 5,623) and a vapour pressure of 40 Pa at 25°C. At the production site the substance is filled into flexible IBCs at an ambient temperature of 25°C. The amount of substance added to the IBC is 1,000 kg.

The volume of air displaced during filling is estimated using Equation 34.

$$Vol_{air\_disp} = \frac{M_s}{RHO_s} \times D \qquad \text{Equation 34}$$

Using Equation 35, the emission to air from each filling event can be estimated.

$$E_{loading\_dust} = \frac{Vol_{air\_disp} \times Conc_{air}}{1\times10^6} \qquad \text{Equation 35}$$

$E_{loading\_dust}$	Emission per event to air from filling	kg event^{-1}	
Vol_{air_disp}	Volume of air displaced during filling of tanker		Calculate from Equation 34
M_s	Mass of substance added to IBC. This is taken to be the net weight of the vessel for complete filling of the vessel	1,000 kg unit load^{-1}	Substance data
RHO_s	Density of substance	1,000 kg m^{-3}	Substance data
D	Dispersion factor to take account of the fact that the volume of air displaced may be higher than the volume of substance added	1,000	Suggested default in the range 1-10,000 (Section 5.4.2)
$Conc_{air}$	Concentration of substance in air	10 mg m^{-3}	Default for particle size < 40 µm (Section 5.4.2)
	Conversion factor between kg and mg	1×10^6 mg kg^{-1}	

$Vol_{air\_disp} = (1{,}000/1{,}000) \times 1{,}000 = 1{,}000$ m^3.

$E_{loading\_dust} = 1{,}000 \times 10/1\times10^6 = 0.01$ kg/event.

The total number of IBCs containing the substance is estimated using Equation 10.

$$N_{s\_IBC} = \frac{Q_{total\_reg} \times 1{,}000}{RHO_s \times V_{IBC}} = \frac{V_{total\_reg}}{V_{IBC}} \qquad \text{Equation 10}$$

N_{s_IBC}	Number of IBCs containing the substance (or preparation) used in a region/country		
Q_{total_reg}	Total amount of substance (or preparation) produced or used in a region/country	1×10^6 kg year^{-1}	Substance data
V_{IBC}	Volume of IBC used	1,000 litres	Default (Section 2.3)
RHO_s	Density of substance (or preparation)	1,000 kg m^{-3}	Substance data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$N_{s\_IBC} = 1\times10^6 \times 1{,}000/(1{,}000 \times 1{,}000) = 1{,}000$.

The total emission from the production site during filling of the IBC is therefore 1,000×0.01 = 10 kg/year.

The emission from each emptying event can be estimated using Equation 38.

$$E_{unloading\_dust} = \frac{Vol_{air\_disp} \times Conc_{air}}{1 \times 10^6} \qquad \text{Equation 38}$$

$E_{unloading\_dust}$	Emission per event to air from emptying	kg event^{-1}	
Vol_{air_disp}	Volume of air displaced during emptying	1,000 m^3	Calculated from Equation 34 above
$Conc_{air}$	Concentration of substance in air	10 mg m^{-3}	Default for particle size < 40 µm (Section 5.4.2)
	Conversion factor between kg and mg	1×10^6 mg kg^{-1}	

$E_{unloading\_dust} = 1{,}000 \times 10 / 1 \times 10^6 = 0.01$ kg/event.

The IBCs are emptied only at downstream user sites, and the maximum number of IBCs used per day is two. Thus, the daily emission during emptying at a downstream user site is 2×0.01 = 0.02 kg/day.

The total number of IBCs containing the substance is 1,000 (see above). Therefore the country-wide emission from emptying IBCs is 1,000×0.01 = 10 kg/year.

Once emptied, all of the IBCs are sent back to the manufacturer for re-use without cleaning.

5.13.7 Example 7 – emissions to air when loading a road tanker (no vapour balancing)

Dedicated road tankers are used to transport a substance with a vapour pressure of 500 Pa at 20°C and a density of 900 kg m^{-3}. The method of filling used is top loading and tankers are unloaded at the site of delivery without using vapour balancing. Equation 14 can be used to estimate the emissions to air. The capacity of the tanker is taken to be 25,000 kg by default.

$$E_{loading\_top\_no\_vapour\_balance} = 0.94 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 14}$$

$E_{loading\_top\_no\_vapour\_balance}$	Emission per event to air from filling the tanker, with no vapour balancing at the site of delivery	kg event^{-1}	
M_s	Mass of substance added to the tank. This is taken to be equal to the net weight of the tanker for complete filling of the tanker.	25,000 kg unit load^{-1}	Default (Section 5.2)
RHO_s	Density of substance	900 kg m^{-3}	Substance data
VP_s	Vapour pressure of substance	500 Pa	Substance data
	Conversion factor between Pa and atmospheres	1×10^5 Pa atm^{-1}	

$$E_{loading\_top\_no\_vapour\_balance} = 0.94 \times \frac{25{,}000}{900} \times \frac{500}{1 \times 10^5} = 0.13 \text{ kg/event.}$$

5.13.8 Example 8 – emissions to air when loading a road tanker (with vapour balancing)

A substance with a vapour pressure of 264 Pa is loaded into a road tanker, with vapour balancing at the site of delivery. The density of the substance is 840 kg m^{-3}. Equation 16 is used to estimate the emissions to air per loading event. The capacity of the tanker is taken to be 25,000 kg by default.

$$E_{loading\_vapour\_balance} = 2.28 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 16}$$

$E_{loading\_vapour\_balance}$	Emission per day to air from filling the tanker, with vapour balancing	kg event^{-1}	
M_s	Mass of substance added to the tank. This is taken to be equal to the net weight of the tanker for complete filling of the tanker.	25,000 kg unit load^{-1}	Default (Section 5.2)
RHO_s	Density of substance	840 kg m^{-3}	Substance data
VP_s	Vapour pressure of substance	264 Pa	Substance data
	Conversion factor between Pa and atmospheres	1×10^5 Pa atm^{-1}	

$$E_{loading\_vapour\_balance} = 2.28 \times \frac{25{,}000}{840} \times \frac{264}{1 \times 10^5} = 0.18 \text{ kg/event.}$$

5.13.9 Example 9 – emissions to air when loading a rail tanker

A volatile substance with a vapour pressure of 1,000 Pa is transported by rail tanker. The emissions to air during a single loading event can be estimated using Equation 17. The density of this substance is 850 kg m^{-3}. The size of the tanker is taken to be 130,000 kg by default.

$$E_{loading} = 1.05 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 17}$$

$E_{loading\_vapour\_balance}$	Emission per day to air from filling the tanker, with vapour balancing	kg event^{-1}	
M_s	Mass of substance added to the tank. This is taken to be equal to the net weight of the tanker for complete filling of the tanker.	130,000 kg unit load^{-1}	Default (Section 5.2)
RHO_s	Density of substance	850 kg m^{-3}	Substance data
VP_s	Vapour pressure of substance	1,000 Pa	Substance data

	Conversion factor between Pa and atmospheres	1×10^{5} atm^{-1}	Pa

$$E_{loading} = 1.05\times\frac{130{,}000}{850}\times\frac{1{,}000}{1\times10^{5}} = 1.6\,\text{kg/event.}$$

Equation 18 is used to estimate the losses from open hatches prior to and post loading.

$$E_{hatch} = 0.03\times\frac{M_s}{RHO_s}\times\frac{VP_s}{1\times10^{5}} \qquad \text{Equation 18}$$

$$E_{hatch} = 0.03\times\frac{130{,}000}{850}\times\frac{1{,}000}{1\times10^{5}} = 0.05\ \text{kg/event.}$$

5.13.10 Example 10 – emissions to air from filling an underground storage tank

A substance is stored in an underground horizontal storage tank of capacity 20,000 litres of with vapour balancing. The vapour pressure of the substance is 10 Pa. The emission per event to air from complete filling of the tank is estimated using Equation 32.

$$E_{tank\_filling\_underground\_storage\_no\_vapour-balance} = 0.11\times\frac{V_s}{1{,}000}\times\frac{VP_s}{1\times10^{5}} \qquad \text{Equation 32}$$

$E_{tank\_filling}$	Emission per event to air from filling the tank	kg event^{-1}	
V_s	Volume of substance added to tank	20,000 litres unit load^{-1}	Substance data
VP_s	Vapour pressure of substance	10 Pa	Substance data
	Conversion factor between Pa and atmospheres	1×10^{5} Pa atm^{-1}	
	Conversion factor between m^{3} and litres	1,000 litres m^{-3}	

$$E_{\tan k\_filling\_underground\_storage\_vapour\ \ balance} = 0.11\times\frac{20{,}000}{1{,}000}\times\frac{10}{1\times10^{5}} = 0.0002\ \text{kg/event.}$$

5.13.11 Example 11 – emissions to air from emptying a storage tank

A pressurised vertical storage tank contains 1,000,000 litres of a volatile substance with a molecular weight of 60 g/mole. The substance is pure and has a vapour pressure of 2,000 Pa at 25°C. The emission per event to air from emptying the storage tank can be estimated using Equation 36.

$$E_{emptying\_comp} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1000} \qquad \text{Equation 36}$$

$E_{emptying\_comp}$	Emission per event to air of chemical from emptying the storage tank	kg event^{-1}	
V_s	Volume of substance emptied	1×10^{6} litres unit load^{-1}	Substance data
R	Ideal gas constant	8.314 J K^{-1} mol^{-1}	
T	Temperature	298 K	Default
x_{comp}	Mole fraction of chemical (component) in the liquid	1	Default for pure substances
VP_{comp}	Vapour pressure of chemical (component) at temperature T	2,000 Pa	Substance-specific data
MW_{comp}	Molecular weight of chemical (component)	60 g mole^{-1}	Substance-specific data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	
	Conversion factor between kg and g	1,000 g kg^{-1}	

$$E_{emptying\_comp} = \frac{1{,}000{,}000 \times 1 \times 2{,}000}{8.314 \times 298 \times 1{,}000} \times \frac{60}{1{,}000} = 48 \ \text{kg/event.}$$

5.13.12 Example 12 – emissions to air from filling a storage tank

A pressurised spherical storage tank, capacity 3,000,000 litres is filled with a pure substance with a vapour pressure of 980 Pa at 298 K. The molecular weight of the substance is 100 g/mole.

Equation 30 is used to estimate the mass of the substance emitted to air.

$$E_{tank\_filling\_comp} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1{,}000} \qquad \text{Equation 30}$$

$E_{tank\_filling\_comp}$	Emission per event to air of chemical (component) from filling the storage tank	kg event^{-1}	
V_s	Volume of substance filled	3×10^{6} litres unit load^{-1}	Substance data
x_{comp}	Mole fraction of chemical (component) in the liquid	1	Default for pure substances
VP_{comp}	Vapour pressure of chemical (component) at temperature T	980 Pa	Substance-specific data
MW_{comp}	Molecular weight of chemical (component)	100 g mole^{-1}	Substance-specific data

	Conversion factor between m^3 and litres	1,000 litres m^{-3}	
	Conversion factor between kg and g	1,000 g kg^{-1}	

$$E_{\tan k\_filling\_comp} = \frac{3{,}000{,}000\times 1\times 980}{8.314\times 298\times 1{,}000}\times\frac{100}{1{,}000} = 119 \text{ kg/event.}$$

5.13.13 Example 13 – emissions to air from loading and transportation in a seagoing vessels

A substance with a vapour pressure of 0.01 Pa at 20°C is loaded into a seagoing vessel. This cargo is the same as the one previously carried and the tanks were ballasted with seawater. 1.5×10^7 m^3 of the substance is loaded into the vessel. The emission to air from filling the tanker was calculated using Equation 20.

$$E_{loading\_sea\_volatile\_ballasted} = 0.59\times\frac{M_s}{RHO_s}\times\frac{VP_s}{1\times10^5} \qquad \text{Equation 20}$$

$E_{loading\_sea\_volatile\_ballasted}$	Emission per event to air from filling the vessel	kg $event^{-1}$	
VP_s	Vapour pressure of substance	0.01Pa	Substance data
	Conversion factor between Pa and atmospheres	1×10^5 Pa atm^{-1}	

For this example, the volume of the substance is given as 1.5×10^7 m^3. This is equivalent to M_s/RHO_s.

$$E_{loading\_sea\_volatile\_ballasted} = 0.59\times 15{,}000{,}000\times\frac{0.01}{1\times10^5} = 0.89 \text{ kg/event.}$$

The emissions of this substance during 28 days transportation can be estimated using Equation 27.

$$E_{breathing\_sea\_transport} = 0.125\times\frac{M_s}{RHO_s}\times\frac{VP_s}{1\times10^5}\times t \qquad \text{Equation 27}$$

$$E_{breathing\_sea\_transport} = 0.125\times 15{,}000{,}000\times\frac{0.01}{1\times10^5}\times 28 = 5.3 \text{ kg/voyage.}$$

5.13.14 Example 14 – emissions to air from loading an inland barge

An inland barge tanker, capacity 1.6×10^6 litres, is filled with a substance of vapour pressure 1 Pa. The density of the substance was 670 kg m^{-3}. The cargo previously carried was the same as the one being loaded. The emissions to air from filling the tanker can be estimated using Equation 24.

$$E_{loading\_barge\_volatile\_uncleaned} = 1.29 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 24

$E_{loading}$	Emission per event to air from filling the barge	kg event^{-1}	
M_s	Mass of substance added to barge	1.6×10^6 kg unit load^{-1}	Substance data
VP_{comp}	Vapour pressure of substance	1 Pa	Substance data
RHO_s	Density of substance	670 kg m^{-3}	Substance data
	Conversion factor between Pa and atmospheres	1×10^5 Pa atm^{-1}	

$$\mathrm{E}_{\mathrm{loading\_barge\_volatile\_uncleaned}} = 1.29 \times \frac{1{,}600{,}000}{670} \times \frac{1}{1 \times 10^5} = 0.031 \text{ kg/event.}$$

5.13.15 Example 15 – filling, emptying and cleaning a road tanker

A road tanker is filled with a substance at ambient temperature. The density of the substance is 950 kg m^{-3} and the method of filling is bottom loading. There is no vapour balancing at the site of delivery and the vapour pressure of the substance is 5 Pa. The molecular weight of the substance is 65 g/mole and the volume of this substance added to the tanker is estimated from the density and mass (25,000 kg) to be 26.32 m^3 tanker^{-1}or 26,320 litres tanker^{-1}.

Firstly, the emission per event to air from filling the tanker is calculated using Equation 15.

$$E_{loading\_bottom\_no\_vapour\_balance} = 0.86 \times \frac{M_s}{RHO_s} \times \frac{VP_s}{1 \times 10^5}$$ Equation 15

$E_{loading}$	Emission per event to air of chemical from filling the tanker	kg event^{-1}	
M_s	Mass of substance added to the tanker	25,000 kg unit load^{-1}	Substance data
VP_s	Vapour pressure of substance	5 Pa	Substance data
RHO_s	Density of substance	950 kg m^{-3}	Substance data
	Conversion factor between Pa and atmospheres	1×10^5 Pa atm^{-1}	

$$E_{loading\_bottom\_no\_vapour\_balance} = 0.86 \times \frac{25{,}000}{950} \times \frac{5}{1 \times 10^5} = 0.001 \text{ kg/event.}$$

The emissions per event to air of the chemical from emptying the tanker at ambient temperature can be estimated using Equation 36.

$$E_{emptying\_comp} = \frac{V_s \times x_{comp} \times VP_{comp}}{R \times T \times 1{,}000} \times \frac{MW_{comp}}{1000}$$ Equation 36

$E_{emptying\_comp}$	Emission per event to air of chemical (component) from emptying the tanker	kg $event^{-1}$	
V_s	Volume of substance emptied	26,320 litres (26.32 m^3) unit $load^{-1}$	Substance data
R	Ideal gas constant	8.314 J K^{-1} mol^{-1}	
T	Temperature	298 K	Default
x_{comp}	Mole fraction of chemical (component) in the liquid	1	Default for pure substances
MW_{comp}	Molecular weight of chemical (component)	65 g $mole^{-1}$	Substance data
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	
	Conversion factor between kg and g	1,000 g kg^{-1}	

$$E_{emptying\_comp} = \frac{26{,}320 \times 1 \times 5}{8.314 \times 298 \times 1{,}000} \times \frac{65}{1{,}000} = 0.003 \text{ kg/event.}$$

The emissions to water from cleaning the road tanker can be estimated using Equation 41. It is assumed here that one tanker containing this substance is cleaned at the site per day.

$$E_{road\_tanker\_cleaning\_water} = M_s \times F_{resid} \times N$$ Equation 41

$E_{road\_tanker\_cleaning\_water}$	Emission per day to water from road tanker cleaning	kg day^{-1}	
M_s	Mass of substance in tanker when full	25,000 kg $tanker^{-1}$	Substance data
F_{resid}	Fraction of full load of substance remaining in tanker before cleaning process	0.002	Default for liquids (Section 5.9.2)
N	Number of tankers containing the substance cleaned at a site per day	1 tanker day^{-1}	Default (Section 5.9.1)

$E_{road\_tanker\_cleaning\_water}$ = 25,000 x 0.002 x 1 = 50 kg/day or 15,000 kg/year assuming 300 working days per year.

As well as emissions to water, emissions to air could also theoretically occur during tanker cleaning and these emissions can be estimated using Equation 43.

$$E_{road\_tanker\_cleaning\_air} = \frac{VP_s \times V_t \times MW \times N}{Atm. \times MV}$$ Equation 43

$E_{road\_tanker\_cleaning\_air}$	Emission per day to air from road tanker cleaning	kg day^{-1}	
N	Number of tankers containing the substance cleaned at a site per day	1 tanker day^{-1}	Default (Section 5.9.1)
VP_s	Vapour pressure of the substance	5 Pa	Substance data
V_t	Volume of substance in tanker	26,320 litres (26.32 m^3) tanker^{-1}	Substance data
MW	Molecular weight of substance	65 g mole^{-1}	Substance data
MV	Molar volume of a gas	22.41 l mole^{-1}	Default
$Atm.$	Atmospheric pressure	101,325 Pa	Default

$$E_{road\_tanker\_cleaning\_air} = \frac{5 \times 26{,}320 \times 65 \times 1}{101{,}325 \times 22.4} = 3.8 \text{ kg/event.}$$

5.13.16 Example 16 – emissions from filling, storing and emptying an underground storage tank

An underground storage tank of capacity 25,000 litres is filled with a pure liquid of vapour pressure 50 Pa. The molecular weight of the substance was 115 g/mole. There is no vapour balancing at the site, so Equation 31 is used to estimate the emissions to air from this event.

$$E_{tank\_filling\_underground\_storage\_no\_vapour-balance} = 2.44 \times \frac{V_s}{1{,}000} \times \frac{VP_s}{1 \times 10^5} \quad \text{Equation 31}$$

$E_{tank\_filling}$	Emission per event to air from filling the tank	kg event^{-1}	
V_s	Volume of substance added to tanker	25,000 litres tanker^{-1}	Default (Section 5.2)
VP_s	Vapour pressure of substance	50 Pa	Substance data
	Conversion factor between Pa and atmosphere	1×10^5 Pa atm^{-1}	
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$$E_{tank\_filling\_underground\_storage\_no\_vapour\ \ balance} = 2.44 \times \frac{25{,}000}{1{,}000} \times \frac{50}{1 \times 10^5} = 0.031 \text{ kg/event.}$$

Emissions per day to air from breathing loss from storage can be estimated using Equation 39.

$$E_{breathing\_underground\_storage\_air} = 0.33 \times \frac{V_s}{1{,}000} \times \frac{VP_s}{1 \times 10^5} \qquad \text{Equation 39}$$

$E_{breathing\_underground}$	Emission per day to air from	kg day^{-1}	

$_{storage\_air}$			
V_s	Volume of substance added to tanker	25,000 litres tanker^{-1}	Default (Section 5.2)
VP_s	Vapour pressure of substance	50 Pa	Substance data
	Conversion factor between Pa and atmosphere	1×10^5 Pa atm^{-1}	
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	

$$E_{breathing\_underground\_storage\_air} = 0.33\times\frac{25{,}000}{1{,}000}\times\frac{50}{1\times10^5} = 0.004 \text{ kg/day or 1.5 kg/year.}$$

Finally, emissions from emptying the storage tanker were estimated using Equation 36.

$$E_{emptying\_comp} = \frac{V_s\times x_{comp}\times VP_{comp}}{R\times T\times 1{,}000}\times\frac{MW_{comp}}{1000} \qquad \text{Equation 36}$$

$E_{emptying\_comp}$	Emission per event to air of the chemical from emptying the storage tanker	kg event^{-1}	
MW	Molecular weight of substance	115 g mole^{-1}	Substance data
R	Ideal gas constant	8.314 J K^{-1} mol^{-1}	
T	Temperature	298 K	Default
	Conversion factor between m^3 and litres	1,000 litres m^{-3}	Substance data
	Conversion factor between kg and g	1,000 g kg^{-1}	

$$E_{emptying\_comp} = \frac{25{,}000\times1\times50}{8.314\times298\times1{,}000}\times\frac{115}{1{,}000} = 0.058 \text{ kg/event.}$$

6. FURTHER CONSIDERATION OF EMISSION CONTROL MEASURES FOR STORAGE TANKS

In addition to the emission control measures taken into account in the development of the emission scenario document, a number of other measures can be used, particularly for storage tanks. These are discussed below.

6.1 Storage tanks

Breathing losses from above ground fixed roof storage tanks depend to some extent on daily changes in temperature (and hence changes in the volume of stored liquid). The colour of the storage tank influences the amount of thermal or light radiation adsorbed. The European Commission (2004) estimated that white painted tanks have the lowest emissions and calculated that emissions could potentially be reduced by between 15 and 82 per cent (depending on the tank size, turnover and products stored) by changing the tank colour from medium grey to white, with no other emission control measures fitted. Similarly, solar shields can be used to reduce the amount of solar radiation reaching the tank. The estimated reduction in emissions (compared to a mid-grey tank with no other emission control measures fitted) from the use of solar shields is estimated to be in the range 44 to 49 per cent (European Commission, 2004).

In floating roof tanks, a rim seal is used to fill the gap between the outer pontoon of the floating roof and the tank shell. All floating roof tanks contain such a seal (known as the primary seal), but it is also possible to install a secondary seal above the primary one to further reduce emissions. The effectiveness of the seal depends on the ‘roundness’ of the tank (which in turn depends mainly on the settlement of the tanks and hence on the foundation design). Therefore, the effectiveness of the secondary seal depends to a large extent on site-specific factors, along with the type of product stored, turnover and so on.

Within the EU, Council Directive 94/63/EC of 20th December 1994 (relating to the control of volatile organic compound emissions resulting from the storage of petrol and its distribution from terminals to service stations) requires that tanks with external floating roofs must be equipped with both a primary and secondary seal.

Other sources of emissions from both floating and fixed roof storage tanks include via fittings on the tank, such as slotted still wells and roof support legs on external floating roof tanks. These fittings can act as pathways for the escape of vapours from the tanks. European Commission (2004) outlines some methods that can be used to reduce the emissions from these sources.

For fixed roof tanks of volume > 50 m^3 storing products with a vapour pressure > 1 kPa at ambient temperature, the installation of an internal floating roof can lead to a reduction in emissions of at least 90 per cent (European Commission, 2004).

Pressure relief valves, although usually installed as a safety device to fixed roof tanks, can also act to limit emissions to the environment during filling and in particular from breathing losses. The use of pressure relief valves is common practice on tanks with a volume < 50 m^3 and their effectiveness is very specific to the storage conditions used (European Commission, 2004).

Vapour balancing is a technique whereby the vapours displaced during the transfer of a liquid are collected from the receiving tank and returned to the delivery tank. Such systems can reduce emissions from the transfer process by up to 80 per cent, depending on the number of tank turnovers. Vapour balancing requires both the delivery tank and receiving tank to be of the atmospheric pressure fixed roof type, and is commonly used on such tanks containing chemicals (European Commission, 2004). Vapour balancing is also appropriate to other types of storage such as floating storage and atmospheric mined caverns.

Another method that can be used to reduce breathing losses from fixed roof tanks is the use of vapour holders (flexible diaphragm tanks). These holders store the vapours produced from the main storage tank during out-breathing as the temperature rises, and then release them back into the tank when the temperature reduces again. Emission reductions of between 33 and 100 per cent are obtained by incorporating vapour holders onto fixed roof tanks, with the highest reduction in total emissions occurring when the breathing losses contribute a very high proportion to the total losses from the tank (that is, when the tank turnover is very small). The effectiveness is specific to the actual operating conditions of the tank and the amount of solar radiation. Vapour holders are used for storing some petroleum products (European Commission, 2004).

In some cases, the vapours emitted from storage tanks (and sometimes road tankers) can be collected and subjected to further treatment (European Commission, 2004). Examples of such systems include end-of-line treatment whereby the vapours are collected and fed to a thermal oxidiser or vapour recovery unit via pipework. These methods are only really practical in situations where the vapours can be collected relatively easily, for example from fixed roof tank vents.

6.2 Information from other EU countries

Legislation regarding the transport of hazardous goods is generally applicable throughout the EU. As much of this ESD has been derived based on generic information, the scenarios should also be applicable throughout the EU. However, specific requirements may exist in some countries, examples of which are outlined below.

In the Netherlands, internal floating roofs (with an emission reduction efficiency of greater than 97 per cent compared with the fixed roof tank) are required if the substance being stored has a vapour pressure of ≥ 1 kPa at 20°C and the tank has a volume of ≥ 50 m^3, except if the substance is toxic. In this case, the tank should be connected to a vapour treatment installation (European Commission, 2004).

In Germany, the TA Luft requires that for new bulk storage installations and for substances with a vapour pressure of > 1.3 kPa at 20°C (or for specified substances), points of emission from the storage tank should be connected to a vapour treatment installation, a vapour collection pipe or a vapour recovery unit. However, crude oil to be stored in tanks with a volume of > 20,000 m^3 may also be stored in floating roof tanks sealed effectively at their edges or in fixed roof tanks with internal floating roofs (emission reduction efficiency of > 97 per cent). In addition, an internal floating roof (emission reduction efficiency > 97 per cent) may also be used at existing installations provided the storage tank does not contain a substance that is carcinogenic/ mutagenic/reprotoxic. Fixed roof tanks with a volume < 300 m^3 do not need to be connected to a vapour collection pipe or a vapour treatment installation, provided the substance stored does not meet any of the criteria for classified substances and specified limit values.

7. DATA GAPS AND UNCERTAINTIES

A number of data gaps and areas of uncertainty are indicated in the various sections of this document. This section brings these together and adds some more general comments. These are not in any specific order, although the first point is probably the most important for the user of this document.

A key question to address in using this document is the extent to which releases described in this document may already be included in other estimates of emissions. This relates particularly to sites of chemical use. Where estimates of emissions from such sites are based on releases from individual process elements then the releases due to transport and storage are likely to be additional. If release estimates or factors are based on overall releases from a site, then these are likely to incorporate at least some elements of emission from unloading, loading and cleaning operations. Hence care is needed in using this document for such sites to avoid possible double counting. The situation is different for sites dedicated to cleaning tankers, drums etc. which will not be addressed under other ESDs.

Defining the scale of operations related to this ESD for representative sites is difficult, and will lead to some uncertainties. This is particularly true of sites producing and using chemicals, although it may be possible to use information from specific areas of chemical use (from another ESD if available) to develop a generic transport and storage scenario for that area if the range of methods used is limited. Information on the scale of operations at cleaning sites has been included and this allows local scenarios to be considered. Information of a similar type from other countries would increase the applicability of the ESD.

The information on releases or methods available for calculating them tends to be better for larger containers, so that, for example, tankers are better covered than drums. In particular, there is limited information on losses of liquids, vapours and particulates from filling and emptying drums.

There is little information on the losses of solid materials from transfer and handling methods; such losses would be expected to be localised.

In estimating the losses from cleaning of tankers, drums etc. a number of assumptions have been made relating to the degree to which cleaning solutions are re-used, and the rate at which they are topped up. Further information on current practice in this area would be useful.

Simplified approaches have been developed to identify the most likely combinations of transport, packaging and storage for a given situation. As indicated in the text, other factors are likely to be important. Examples of real situations may be useful in the future development of this area. It is of course possible that the same substance may be handled in different ways by different users, so that many different possibilities may exist.

Very little information is available on pipelines. This information indicates that releases are likely to be low in general. It would be useful to have information on whether it is possible that there are emissions related to maintenance operations, and if so how often these are carried out.

There is uncertainty over the effective volume of air displaced when filling and emptying containers, for vapour and dust emissions.

Better information on the efficiencies of abatement techniques and their frequency of use in different areas would be useful.

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This document contains a number of links to internet sites which were last checked in March 2006. These links may change in the future and the parent website should be consulted to locate the new location of the information, should broken links occur.

9. GLOSSARY

ADN	European Agreement concerning the Carriage of Dangerous Goods by Inland Waterways
ADR	European Agreement concerning the Carriage of Dangerous Goods by Road
API	American Petroleum Institute
BAT	Best available technique
BCDTA	British Chemical Distributors and Traders Association
BREF	Reference Document on Best Available Techniques
CORINAIR	CORe Inventory of Air emissions
CPI	Corrugated plate interceptor
Defra	Department for Environment, Food and Rural Affairs
EFRT	External floating roof tank
EMEP	The co-operative program for monitoring and evaluation of the long-range transmission of air pollutants in Europe
ESD	Emission scenario document
EUROPIA	European Petroleum Industry Association
FRT	Fixed roof tank
GRP	Glass-fibre reinforced polyester
IBC	Intermediate bulk container
IMDG	International Maritime Dangerous Goods Code
IPA	Industrial Packaging Association
IPPC	Integrated Pollution Prevention and Control
NMVOC	Non-methane volatile organic compound
NPI	National Pollutant Inventory
NRTCA	National Road Tanker Cleaning Association
OPPT	Office of Pollution Prevention and Toxics
PPI	Parallel plate interceptor
PVRVs	Pressure/vacuum relief valves
RID	Regulations concerning the International Carriage of Dangerous Goods by Rail
SIA	Solvent Industry Association
TGD	Technical Guidance Document
TSP	Total suspended particulates
UKPIA	United Kingdom Petroleum Industry Association
UN	United Nations
USEPA	United States Environmental Protection Agency
UV	Ultra violet
VOC	Volatile organic compound

APPENDIX A: UN RECOMMENDATIONS ON THE TRANSPORT OF DANGEROUS GOODS

The first version of the UN Recommendations was published in 1956. These have been regularly updated by the United Nations Economic and Social Council's Committee of Experts on the Transport of Dangerous Goods. In 1996, the Committee adopted a first version of Model Regulations on the Transport of Dangerous Goods. The committee was reconfigured in 1997 to include subgroups on the classification and labelling of chemicals.

This appendix provides a brief summary of the main parts of the regulations relevant for this ESD. The regulations should be consulted for the specific requirements that relate to a given chemical.

The recommendations cover different classes of substances. Chapter 2 of the regulations defines these classes and any subdivisions. Table A 1 gives the substances covered in each class.

Table A 1 Classes for substances

Class	Substances
1	Explosives.
2	Gases.
3	Flammable liquids.
4	Flammable solids. Substances liable to spontaneous combustion. Substances which in contact with water emit flammable gases.
5	Oxidising substances. Organic peroxides.
6	Toxic and infectious substances.
7	Radioactive materials.
8	Corrosive substances.
9	Miscellaneous dangerous substances and articles.

Chapter 3 of the UN Recommendations includes the dangerous goods list. This list covers the dangerous goods most commonly carried, but it is not exhaustive. The list covers, as far as practicable, all dangerous substances of commercial importance, and contains the following information for each substance listed:

- the UN number assigned to the article or substance under the United Nations system;
- name and description in the proper shipping name;
- class or division the substance or article belongs to;
- subsidiary risk, which contains the class or division number of any important subsidiary risks which have been identified;
- UN packing group (I, II, or III; see below);
- special provisions, with a number referring to any special provision(s) relevant to the article or substance;
- limited quantities, which provides the maximum quantity per inner packaging authorised for transport of the substance concerned;

- packing instruction, with an alpha numeric code which refers to the relevant packing instructions and indicates the packaging which may be used for the transport of substances and articles;
- special packing provisions given by an alpha numeric code;
- portable tank and bulk containers/instructions;
- portable tank and bulk containers/special provisions.

An example of an entry in the dangerous goods list and an explanation is given in Table A 2 below.

Table A 2 Example of an entry in the dangerous goods list

Heading	Entry	Explanation
UN No	3461	
Name and description	Aluminium alkyl halides, solid	Proper shipping name.
Class or division	4.2	Substances liable to spontaneous combustion.
Subsidiary risk	4.3	Substances which in contact with water emit flammable gases.
UN packing group	I	Substance presenting high danger.
Special provision	320	320 – States that this entry will be withdrawn in 2007.
Limited quantities	None	May not be transported under the requirement of Chapter 3.4 of the regulations.
Packing instructions	P404	Gives details of packaging that may be used as detailed in Table P404 of Chapter 4 of the regulations.
Special packing provisions		None for this substance.
Portable tanks and bulk containers - Instructions	T21	Specifies the minimum test pressure, the minimum shell thickness (in mm reference steel), and the pressure-relief and bottom-opening requirements as detailed in Chapter 4 of the regulations.
Portable tanks and bulk containers – Special provisions	TP7 TP33	TP7 – Specifies that air shall be eliminated from the vapour space by nitrogen or other means. TP 33 – Instruction apply to granular and powdered solids and for solids which are filled and discharged at temperatures above their melting point and which are cooled and transported as a solid mass.

Chapter 4 gives details of packing and tanking provisions. For packing purposes, substances other than those of Classes 1, 2 and 7 and Divisions 5.2 (organic peroxides) and 6.2 (infectious substances) and other than self-reactive substances of Division 4.1 (flammable solids, self-reactive substances and solid desensitised explosives) are assigned to three packing groups in accordance with the degree of danger they present:

Packing group I: Substances presenting high danger;
Packing group II: Substances presenting medium danger;

Packing group III: Substances presenting low danger.

In Chapter 6 of the UN Recommendations, codes for designating types of packaging are given. For each type of packaging, there is a three figure code consisting of a numeral indicating the kind of packaging, a letter indicating the type of material and a numeral indicating the category of packaging. Table A 3 gives details of the codes used to designate different types of packaging taken from Chapter 6.1 for illustration. A similar set of codes is given for other packaging types, for example IBCs (in Chapter 6.5), large packages (in Chapter 6.6) and bulk containers (in Chapter 6.8).

Table A 3 UN designation of different type of packaging

Kind of packing	Material	Category	Code
1. Drums	A Steel	Non-removable head	1A1
		Removable-head	1A2
	B Aluminium	Non-removable head	1B1
		Removable head	1B2
	D Plywood		1D
	G Fibre		1G
	H Plastics	Non-removable head	1H1
		Removable head	1H2
	N Metal, other steel or aluminium	Non-removable head	N1
		Removable head	N2
2. Barrels	C Wooden	Bung type	2C1
		Removable head	2C2
3. Jerricans	A Steel	Non-removable head	3A1
		Removable-head	3A2
	B Aluminium	Non-removable head	3B1
		Removable head	3B2
	H Plastics	Non-removable head	3H1
		Removable head	3H2
4. Boxes	A Steel		4A
	B Aluminium		4B
	C Natural wood	Ordinary	4C1
		With sift-proof walls	4C2
	D Plywood		4D
	F Reconstituted wood		4F
	G Fibreboard		4G
	H Plastics	Expanded	4H1
		Solid	4H2
5. Bags	H Woven plastics	Without inner liner or coating	5H1
		Sift-proof	5H2
		Water resistant	5H3
	H Plastic film		5H4
	L Textile	Without inner liner or coating	5L1
		Sift-proof	5L2

Kind of packing	Material	Category	Code
		Water resistant	5L3
	M Paper	Multiwall	5M1
		Multiwall, water resistant	5M2
6. Composite packaging	H Plastic receptacle	In steel drum	6HA1
		In steel crate or box	6HA2
		In aluminium drum	6HB1
		In aluminium crate or box	6HB2
		In wooden box	6HC
		In plywood drum	6HD1
		In plywood box	6HD2
		In fibre drum	6HG1
		In fibreboard box	6HG2
		In plastics drum	6HH1
		In solid plastics box	6HH2
	P Glass, porcelain or stoneware receptacle	In steel drum	6PA1
		In steel crate or box	6PA2
		In aluminium drum	6PB1
		In aluminium crate or box	6PB2
		In wooden box	6PC
		In plywood drum	6PD1
		In wickerwork drum	6PD2
		In fibre drum	6PG1
		In fibreboard box	6PG2
		In expanded plastics packaging	6PH1
		In solid plastics packaging	6PH2

Chapter 5 of the UN Recommendations gives consignment procedures. Chapter 6 sets out the requirements for the construction and testing of packagings, IBCs, large packagings, portable tanks and bulk containers. Finally, Chapter 7 gives details of the provisions concerning transport operations.

APPENDIX B: LEGISLATION APPLICABLE TO STORAGE OF CHEMICALS IN ENGLAND

The following table lists the legislation that may be relevant to chemical storage installations in England (similar legislation may also apply to storage installations in Wales, Scotland and Northern Ireland). The information is taken from CIRIA (2003) and covers both environmental legislation and health and safety legislation.

Table B 1 Legislation applicable to storage of chemicals in England

Legislation	Environment or health and safety
Anti-pollution Works Regulation	Environment
Chemicals (Hazard Information and Packaging for Supply) Regulations 2002	Health and safety and environment
Confined Spaces Regulation 1997	Health and safety
Construction (Design and Management) Regulations 1994	Health and safety
Contaminated Land Regulations	Environment
Control of Major Accident Hazard Regulations 1999	Health and safety
Control of Pollution (Oil Storage) (England) Regulations 2001	Environment
Control of Substances Hazardous to Health Regulations 1999	Health and safety
Dangerous Substances and Explosive Atmospheres Regulations 2002	Health and safety
Dangerous Substances (Notification and Marking of Sites) Regulations 1990	Health and safety
Electricity at Work Regulations 1989	Health and safety
Environment Act 1995	Environment
Environmental Protection Act 1990	Environment
Environmental Protection (Applications, Appeals and Registers) Regulations 1991	Environment
Environmental Protection (Duty of Care) Regulations 1991	Environment
Environmental Protection (Prescribed Processes and Substances) Regulations 1991	Environment
Fire Certificates (Special Premises) Regulations 1976	Health and safety
Fire Precautions Act 1971	Health and safety
Groundwater Regulations 1998	Environment
Health and Safety at Work Act 1974	Health and safety
Highly Flammable Liquids and Liquefied	Health and safety

Legislation	Environment or health and safety
Petroleum Gases Regulations 1972	
Management of Health and Safety at Work Regulations 1999	Health and safety
Notification of Installations Handling Hazardous Substances Regulations 1982	Health and safety
Petroleum (Consolidation) Act 1928	Health and safety
Petroleum (Mixtures) Order 1929	Health and safety
Planning (Control of Major Accident Hazards) Regulations 1999	Health and safety
Planning (Hazardous Substances) Act 1990	Health and safety
Planning (Hazardous Substances) Regulations 1992	Health and safety
Pollution Prevention and Control Act 1999	Environment
Pollution Prevention and Control Regulations 2000	Environment
Pressure Equipment Regulations 1999	Health and safety
Provision and Use of Work Equipment Regulations 1998	Health and safety
Reporting of Injuries, Disease and Dangerous Occurrences Regulations 1995	Health and safety
Water Industry Act 1991	Environment
Water Resources Act 1991	Environment

In addition to the above legislation, a large number of national and international Codes, Standards and Guidelines apply to the design, construction, inspection and maintenance, and environmental protection measures for various storage systems. These are too numerous to list here, but a comprehensive overview is given in Annex 8.1 of European Commission (2004).

APPENDIX C: POSSIBLE SOURCES OF EMISSIONS FROM TRANSPORT AND STORAGE SYSTEMS

The Reference Document on Best Available Techniques (better known as BREF) in the transport and storage of chemicals (European Commission, 2004) identifies, in general terms, the most important sources of emissions to air, water, soil and waste from a number of operations involved in the transport and storage of chemicals. A scoring system is used in the approach. The scoring system takes into account both the emission volume and the emission frequency. Within the scheme, an emission score of three or more was considered to be a relevant source to the environment.

Table C 1 summarises the scores estimated for various types of transport and storage system. It should be noted that the scores only give an indication of the relative importance of the emission sources within one type of system. Most importantly, the scores given for different types of storage system are not necessarily directly comparable. For example, an emission score of four from a process involved in a given type of storage tank does not necessarily mean that emissions from a process with a similar score but for a different type of system (for example, produce transfer system) are of a similar magnitude.

Table C 1 Emission scores from European Commission (2004)

Transport and storage system	Operation	Estimated emission score	
		Air	Water or waste
Storage tanks and other storage systems - liquids and liquefied gases			
External floating roof tanks	Filling (until roof floats on liquid)	3	
	Standing (breathing)	3	
	Emptying	1-2	
	Cleaning	2	3
	Blanketing		
	Manual gauging	2	
	Sampling	2	0
	Fugitive	3	
	Draining	2	2
Fixed roof tanks (vertical)	Filling	6	
	Breathing	6	
	Emptying	2	
	Cleaning	2	3
	Blanketing	6	
	Manual gauging	2	
	Sampling	2	0
	Fugitive	3	

Transport and storage system	Operation	Estimated emission score	
		Air	Water or waste
	Draining	2	2
Horizontal storage tanks (above ground, atmospheric)	Filling	6	
	Breathing	6	
	Emptying	2	
	Cleaning	2	2
	Blanketing	6	
	Manual gauging	2	
	Sampling	2	0
	Fugitive	3	
	Draining	2	2
Horizontal storage tanks (pressurised)	Filling	2	
	Breathing		
	Emptying		
	Cleaning	2	1
	Blanketing	2	
	Manual gauging		
	Sampling	2	0
	Fugitive	3	
	Draining	4	0
Vertical storage tanks (pressurised)	Filling	2	
	Breathing		
	Emptying		
	Cleaning	2	1
	Blanketing	2	
	Manual gauging		
	Sampling	2	0
	Fugitive	3	
	Draining	4	0
Spheres (pressurised)	Filling	2	
	Breathing		
	Emptying		
	Cleaning	2	1
	Blanketing	2	
	Manual gauging		
	Sampling	2	0
	Fugitive	3	
	Draining	4	0
Mounded storage (pressurised)	Filling	2	
	Breathing		
	Emptying		
	Cleaning	2	1
	Blanketing	2	
	Manual gauging		
	Sampling	2	0
	Fugitive	3	
	Draining	4	0

Transport and storage system	Operation	Estimated emission score	
		Air	Water or waste
Variable vapour space tanks (lifter roof tanks)	Filling	6	
	Breathing	0	
	Emptying	2	
	Cleaning	2	3
	Blanketing		
	Manual gauging	2	
	Sampling	2	0
	Fugitive	3	
	Draining	2	2
Refrigerated storage tanks	Filling	2	
	Breathing		
	Emptying		
	Cleaning	2	
	Blanketing	2	
	Manual gauging		
	Sampling	2	
	Fugitive	2	
	Draining		
Horizontal storage tanks (underground)	Filling	6	
	Breathing	2	
	Emptying	2	
	Cleaning	2	2
	Blanketing	3	
	Manual gauging	2	
	Sampling	2	
	Fugitive	3	
	Draining		1
Mined caverns (atmospheric, fixed waterbed type)	Filling	6	
	Breathing	2	
	Emptying	2	
	Cleaning		
	Blanketing		
	Manual gauging	2	
	Sampling	2	0
	Fugitive	3	
	Draining	2	2
Mined caverns (atmospheric, fluctuating waterbed type)	Filling	1	
	Breathing	1	
	Emptying	2	
	Cleaning		
	Blanketing		
	Manual gauging	2	
	Sampling	2	0
	Fugitive	3	
	Draining	2	2
Mined caverns	Filling	2	

Transport and storage system	Operation	Estimated emission score	
		Air	Water or waste
(pressurised)	Breathing		
	Emptying	2	
	Cleaning		
	Blanketing		
	Manual gauging		
	Sampling		
	Fugitive	2	
	Draining		
Salt leached caverns	Filling	2	
	Breathing		
	Emptying	2	
	Cleaning		
	Blanketing		
	Manual gauging		
	Sampling		
	Fugitive	2	
	Draining		
Floating storage	Filling	6	
	Breathing	6	
	Emptying	2	
	Cleaning	2	3
	Blanketing	6	
	Manual gauging	2	
	Sampling	2	0
	Fugitive	3	
	Draining	2	0
Transfer systems – liquids and liquefied gases			
Aboveground closed piping transfer systems	Filling	4	
	Cleaning	2	2[a]
	Pigging	2	2[a]
	Purging	2	
	Sampling	2	2[a]
	Connecting/disconnecting	2	2[a]
	Opening	2	2[a]
	Fugitive	3	
	Emptying/draining	1	2[a]
	Pressure relief		2[a]
Underground piping transfer systems	Filling	4	
	Cleaning	2	2[a]
	Pigging	2	2[a]
	Purging	2	
	Sampling	2	2[a]
	Connecting/disconnecting	2	
	Opening	2	1[a]
	Fugitive	3	
	Emptying/draining	2	2[a]

Transport and storage system	Operation	Estimated emission score	
		Air	Water or waste
	Pressure relief		2[a]
Product handling in general (e.g. gravity flow, pumps, compressors)	Filling	0	
	Cleaning	0	1[a]
	Pigging		
	Purging		
	Sampling		
	Connecting/disconnecting		
	Opening	1	1[a]
	Fugitive	3	
	Emptying/draining	0	2[a]
	Pressure relief		
Transporter loading/unloading – flexible hose or loading arm	Filling	4	
	Cleaning	2	2[a]
	Pigging	2	2[a]
	Purging	2	
	Sampling	2	2[a]
	Connecting/disconnecting	6	3[a]
	Opening	2	2[a]
	Fugitive	3	
	Emptying/draining	2	2[a]
	Pressure relief		2[a]

Note: a) Emissions to soil or groundwater.