Guidance on VOC Substitution and Reduction for Activities Covered by the VOC Solvents Emissions Directive (Directive 1999/13/EC)

Guidance 6 – Part 2:

Vehicle coating (large series of cars, buses, vans, trucks and truck cabins)

European Commission - DG Environment

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1 Introduction

This guidance addresses vehicle coating in installations with an annual solvent consumption exceeding 15 tonnes and the related cleaning of equipment, presenting options to substitute or reduce the use of VOC and its resulting emissions.

Table 1: Scope definition of the VOC Solvent Emission Directive (SE Directive)

SE Directive – Scope definitions (Annex I)

Vehicle coating is defined as ‘any activity in which a single or multiple application of a continuous film of a coating is applied to vehicles as listed below:

- new cars, defined as vehicles of category M1 in Directive 70/156/EEC (1), and of category N1 in so far as they are coated at the same installation as M1 vehicles,
- truck cabins, defined as the housing for the driver, and all integrated housing for the technical equipment, of vehicles of categories N2 and N3 in Directive 70/156/EEC,
- vans and trucks, defined as vehicles of categories N1, N2 and N3 in Directive 70/156/EEC, but not including truck cabins,
- buses, defined as vehicles of categories M2 and M3 in Directive 70/156/EEC.’

Vehicles as listed above are defined in Directive 70/156/EEC as follows:

- ‘vehicle’ means any motor vehicle intended for use on the road, with or without bodywork, having at least four wheels and a maximum design speed exceeding 25 km/h, and its trailers, with the exception of vehicles which run on rails and of agricultural tractors and machinery.’ (Article 1)
- Category M: Motor vehicles having at least four wheels, or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of passengers.
- Category M1: Vehicles used for the carriage of passengers and comprising no more than eight seats in addition to the driver's seat.
- Category M2: Vehicles used for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum weight not exceeding 5 metric tons.
- Category M3: Vehicles used for the carriage of passengers, comprising more than eight seats in addition to the driver's seat, and having a maximum weight exceeding 5 metric tons.
- Category N: Motor vehicles having at least four wheels, or having three wheels when the maximum weight exceeds 1 metric ton, and used for the carriage of goods.
- Category N1: Vehicles used for the carriage of goods and having a maximum weight not exceeding 3 75 metric tons.
- Category N2: Vehicles used for the carriage of goods and having a maximum weight exceeding 3 75 but not exceeding 12 metric tons.
- Category N3: Vehicles used for the carriage of goods and having a maximum weight exceeding 12 metric tons. (Annex I)

THIS GUIDANCE ADDRESSES THE COATING OF NEW CARS, TRUCK CABINS, VANS AND TRUCKS AS WELL AS BUSES IF A SOLVENT CONSUMPTION OF 15 TONNES PER YEAR IS EXCEEDED

Vehicle refinishing activities and coating of trailers are addressed in a separate guidance document (see guidance 6 – part 1). This is also the case for the coating of new cars, buses, vans, trucks and truck cabins in installations with a solvent consumption ≤ 15 tonnes per year.

Different requirements under the SE Directive apply for original coating of vehicles and parts depending on whether they are coated in the original manufacturing line or away from the original manufacturing line. Please see guidance 6 – part 1 for original coating of road vehicles and the original coating of parts of them if carried out away from the original manufacturing line and carried out with refinishing-type materials.

This activity does not include the coating with metals by electrophoretic and chemical spraying techniques.

The SE Directive lays down the following emission limit values for vehicle coating in installations with an annual solvent consumption exceeding 15 tonnes per year:

Table 2: Emission limit values of the SE Directive for vehicle coating

<table>
<tr><th colspan="4">SE Directive - Emission limit values (ELVs)
(Annex II A – activity No. 6 – Part II)</th></tr>
<tr><th rowspan="2">Activity (annual solvent consumption threshold)</th><th rowspan="2">Production threshold (refers to annual production of coated item)</th><th colspan="2">Total emission limit value</th></tr>
<tr><th>New installations</th><th>Existing installations</th></tr>
<tr><td rowspan="2">Coating of new cars (>15 t)</td><td>> 5000</td><td>45 g/m² or 1,3 kg/body + 33 g/m²</td><td>60 g/m² or 1,9 kg/body + 41 g/m²</td></tr>
<tr><td>≤ 5000 monocoque or > 3500 chassis-built</td><td>90 g/m² or 1,5 kg/body + 70 g/m²</td><td>90 g/m² or 1,5 kg/body + 70 g/m²</td></tr>
<tr><td rowspan="2">Coating of new truck cabins (> 15 t)</td><td>≤ 5000</td><td>65 g/m²</td><td>85 g/m²</td></tr>
<tr><td>> 5000</td><td>55 g/m²</td><td>75 g/m²</td></tr>
<tr><td rowspan="2">Coating of new vans and trucks (>15 t)</td><td>≤ 2500</td><td>90 g/m²</td><td>120 g/m²</td></tr>
<tr><td>> 2500</td><td>70 g/m²</td><td>90 g/m²</td></tr>
<tr><td rowspan="2">Coating of new buses (>15 t)</td><td>≤ 2000</td><td>210 g/m²</td><td>290 g/m²</td></tr>
<tr><td>> 2000</td><td>150 g/m²</td><td>225 g/m²</td></tr>
<tr><td colspan="4">The total emission limit values are expressed in terms of grams of solvent emitted in relation to the surface area of product in square metres and in kilograms of solvent emitted in relation to the number of car bodies produced.
The total emission limit value in the table below refers to all process stages carried out at the same installation from electrophoretic coating, or any other kind of coating process, through to the final wax and polish of top coating inclusive, as well as solvent used in cleaning of process equipment, including spray booths and other fixed equipment, both during and outside of production time.
The surface area of any product dealt with in the table is defined as follows:
The surface area calculated from the total electrophoretic coating area, and the surface area of any parts that might be added in successive phases of the coating process which are coated with the same coatings as those used for the product in question, or the total surface area of the product coated in the installation.
(For calculation of the surface area of the product see SE Directive, Annex II A II)</td></tr>
</table>

Instead of complying with the above ELVs, operators may choose to use a reduction scheme, following the specifications of Annex II (B) of the SE Directive.

Specific requirements apply for VOCs classified as CMR substances[1] as well as for halogenated VOCs which are assigned the risk phrases R40 or R68[2]. There is a general obligation to replace CMR substances – as far as possible – by less harmful substances or preparations within the shortest possible time. In the case of a mass flow ≥10 g/h for VOC classified as CMR substances or ≥100 g/h for halogenated[3] VOC with R40 the ELVs in waste gases are 2 and 20 mg/Nm³ respectively, and these also apply when a reduction scheme is being used.

National legislation may define lower thresholds for solvent consumption, stricter ELVs or additional requirements.

2 Summary of VOC substitution/reduction

The VOC emissions from this activity depend on the coating systems being applied. The greatest reduction in VOC emissions is achieved if solvent-based coating systems can be substituted by powder systems. This is possible for primers and top coats on metal.

HIGHEST VOC REDUCTION CAN BE ACHIEVED BY APPLICATION OF POWDER BASED COATINGS

If powder application is not possible, VOC reduction can still be achieved by the substitution of solvent-based coatings with water-based systems. Water-based coatings are commonly used for electrophoretic dipping (usually containing 1 – 6 % VOC) and also widely used as primers (5 – 6 % VOC) and base coats (10 – 15 % VOC). Furthermore, water-based single-layer top coats (currently containing 11 – 15 % VOC) may be used as well as water-based clear coats (~ 15 % VOC). New top coat systems, aiming at a VOC content of < 10 % VOC, and new clear coat systems are under development.

In cases where for clear coats neither of these reduction options is applicable for quality or process reasons, the solvent content of the conventional coating systems can be reduced. High solid systems can reduce the VOC content of clear coats from ~ 50 – 60 % to ~ 35 %.

In addition the efficiency of coating application can be increased by the use of high rotation bells, or by employing electrostatic spraying.

Other measures to prevent or reduce VOC emissions include

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[1] CMR substances – carcinogenic (R45, R49), mutagenic (R46), or toxic to reproduction (R60, R61)

[2] After the implementation of the SE Directive a revision of the R-phrase R40 took place. The original wording of R40 was: ‘Possible risk of irreversible effects’. The new wording is: ‘Limited evidence of a carcinogenic effect’. In the ‘old’ version mutagenity (cat 3) was included. This mutagenic effect is now covered separately under R68: ‘Possible risk of irreversible effects’. This new risk phrase does not include carcinogenicity. The ‘new’ version of R40 is obviously less restrictive than the old version. Until the SE Directive is adapted to this change, a final decision on which version applies can only be given by the European Court

[3] Halogenated organic solvents are hydrocarbons with one or more of the following halogens: fluorine, chlorine (e.g. trichloroethylene), bromine (e.g. n-propyl bromide) or iodine.

Reduction of coating layers (e.g. substitution of primer by base coats)

- Efficient material use (reduced colour changes, cartridge systems)
- Efficient cleaning techniques (cleaner recovery, 'pig' cleaning[4])
- Appropriate solvent handling
- Substitution of VOC cleaners by VOC-free cleaners
- Concentration of VOC contained in waste gas and waste gas treatment

3 Description of the activity and related industry sectors

In 2005, 20.8 million motor vehicles were produced in Europe (including Russia). During the same year, in the EU, 1,640,769 light commercial vehicles and 549,468 heavy trucks were produced. There are about 154 car production sites, 109 van, truck and truck cabin production sites and 46 bus production sites in Europe. [BREF STS 2007]

Vehicle coatings must meet high performance requirements (particularly stringent for cars, less so for vans, trucks, buses) for:

- long-term protection against corrosion, chemical attack (e.g. bird droppings, acid rain), chipping protection, solar radiation, abrasion in car washes, etc.
- excellent optical surface properties: polish, colour depth, free of cloudiness, faultlessness,
- homogeneity and a consistency in colouring and formation of effects (such as metallic finishes, etc.).

These requirements are achieved by at least three, often four, and up to five paint layers designed to complement each other. In Europe, the following paint layer construction has come to predominate: [BREF STS 2007]

- Pre-treatment of plastics and body parts assembled from metals (e.g. steels pre-treated with phosphate for corrosion resistance)
- Pre-coat: electrophoretic dipping/cathodic electrodeposition
- Underbody protection/seam sealing
- Primer/filler coat
- Top coat: can be made up of base coat and clear coat
- Cavity conservation and, if necessary, conservation for transit.

Generally throughout Europe two-layer top coats are used for cars (rather than one-layer systems). They comprise a base coat and clear coat.

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[4] 'Pigs' are plastic pieces, forced with compressed air through pipes to transport coating remains left over in pipes back to the storage tank. The system is only applicable, where paints are delivered to machinery through pipes and different colours are sent through the same pipe regularly.

Typical coating systems for vans, trucks and truck cabins, are either serial coating (with drying temperatures of about 140 °C) or 2-component paints (with drying temperature of 80 °C). Also a combination of both systems is often used.

The most commonly applied coating techniques for buses are water-based electro coats, electrostatic primers, and different types of top coat

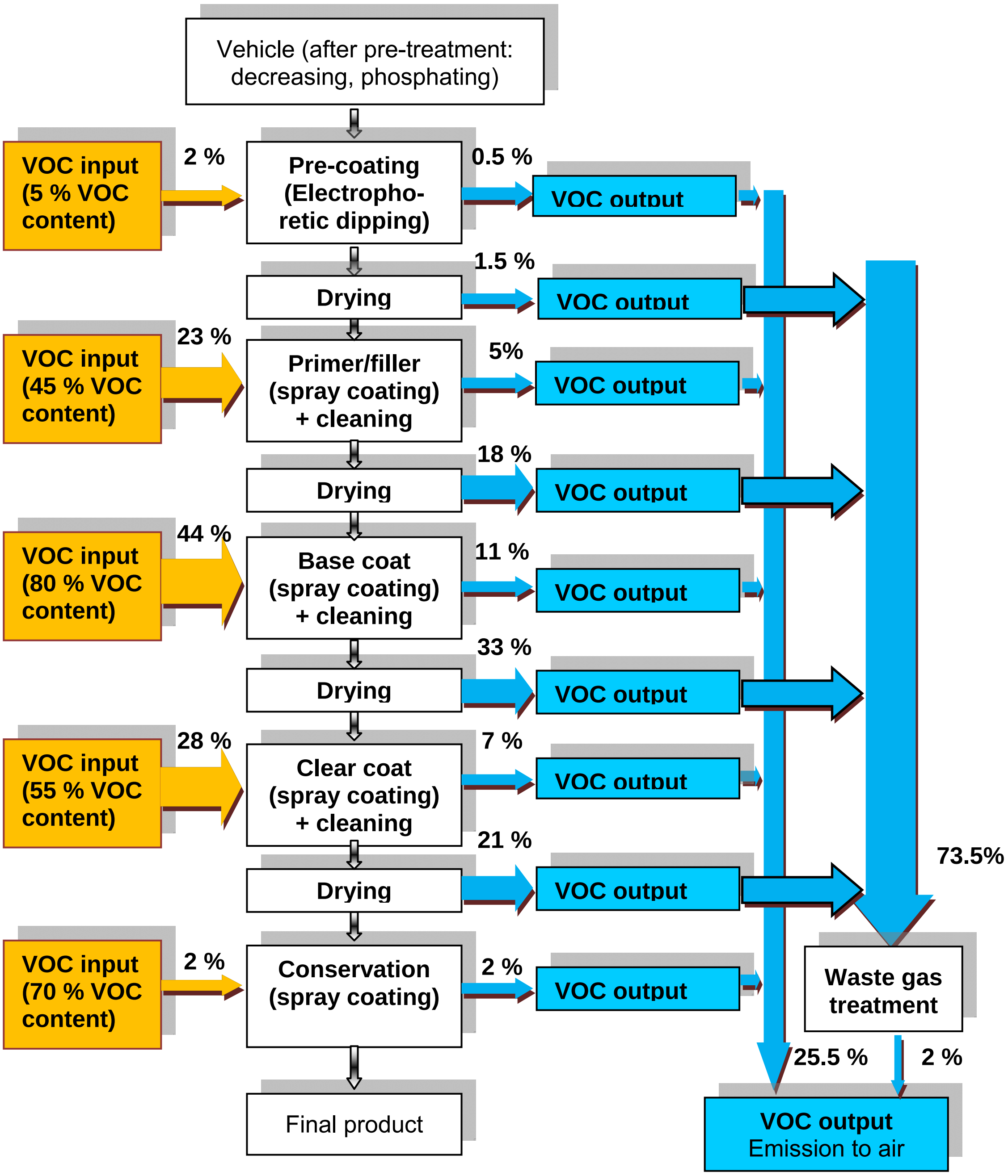
(conventional base coats and electrostatic clear coats). [BREF STS 2007]

4 Technical process description

4.1 Process flow and relevant associated VOC emissions

Coating is applied after pre-treatment (degreasing, phosphating, passivating) with at least 3 up to 5 paint and varnish layers, together with seam sealing, underbody protection and conservation for transport.

Figure 1 shows a flow chart with a schematic overview of all VOC relevant process steps and related emissions found in vehicle coating with conventional solvent-based primer and top coat systems.



based on [DuPont-2 2008]

Figure 1: Typical VOC emissions from conventional vehicle coating

4.2 Process description

4.2.1 Application techniques

In general, vehicle coating has four coating steps. The following table shows the coating products and common application techniques.

Table 3: Application techniques and coatings used for different vehicle productions

Application techniques				
	Pre-coating	**Filler**	**Top-coat (base coat)**	**Top-coat (clear coat)**
Cars Commonly	Water-based electrophoretic dipping	Water-based spray coating	Water-based/solvent based spray coating	Solvent-based (high solid) spray-coating
Seldom used		Powder, solvent-based spray coating		Water-based, powder, powder slurry
Vans Commonly	Water-based electrophoretic dipping	Water-based/solvent-based spray coating		Water-based/solvent-based single-layer spray coating
Seldom used		No filler coating	Water-based/solvent-based base coat spray coating	Water-based/solvent-based clear coat spray coating
Truck cabins Commonly	Water-based electrophoretic dipping			Water-based top-coat spray coating
Seldom used				Solvent-based top-coat spray coating
Truck/bus chassis Commonly	Water-based spray coating	Water-based spray coating	Solvent-based spray coating	Solvent-based (high solid) spray-coating
Seldom used	Water-based electrophoretic dipping	Solvent-based spray coating	Water-based spray coating	Solvent-based single-layer spray coating
Buses Commonly	Water-based electrophoretic dipping	Water-based spray coating	Water-based/solvent based spray coating	Solvent-based (high solid) spray-coating
Seldom used		Powder, solvent-based spray coating		Water-based, powder, powder slurry

[BREF STS 2007] [DuPont-1 2008]

Electrophoretic dipping

In the electrophoretic dipping process an electric current flowing between the immersed working piece and the electrodes of opposite polarity is used to deposit the coating. Cathodic working piece loading systems are commonly used because they offer better resistance against corrosion than do anodic systems (‘CED’ = Cathodic electrophoretic dipping).

The system is commonly used for pre-coating of cars, vans, truck cabins and pre-coated chassis (and, in few cases, for buses).

The dipping reservoir has to contain sufficient liquid for the largest possible item to be completely submerged, and have sufficient capacity to accommodate the increase in the liquid level as the object is dipped. To overcome this problem, a secondary, overflow reservoir can be used, coupled with a mixing system to ensure agitation of the coating material. [Envirowise 2003]

Electrophoretic dipping is an efficient application technique that produces high quality results but investment costs are relatively high. A high level of maintenance, particularly for the paint tanks, is needed to meet quality assurance requirements. [BREF STS 2007]

Conventional high and low pressure spraying

Conventional (non-electrophoretic) spray coating is used for top coats because of its ability to achieve high quality finishes and special surface effects (e.g. metallic or pearl look). Conventional spraying is used for inside parts of vehicles (door insides, bonnet underside) and for metallic coatings (where electrostatic application is not able to produce the desired effect).

Spray coating uses a 'gun', powered by compressed air, to atomise coating material and direct it, as a jet, onto the surface of the working piece. The higher the air pressure the finer the particles of the coating material and the better the quality and the smoothness of the coated surface. On the other hand, the finer the particles, the greater the ease with which they are deflected by the airflow from the coated surface and this leads to increased coating waste (overspray). If the pressure is too low, the surface finish is of poor quality (e.g. an ‘orange peel’ effect is created).

The material efficiency varies from 5 % (for lattice-like working pieces) up to 30 – 60 % (for working pieces with large flat surfaces). Hence, overspray depends on geometry and on the ability of workers or the programming of robots to apply the coating efficiently.

[DFIU 2002] [BREF STS 2007]

Electrostatic spray coating

Electrostatic spray coating is commonly used in the coating of cars, buses, trucks and commercial vehicles. The technique may be used either manually or automatically. It is used for all external vehicle surfaces. Its application for inside parts is difficult because of the Faraday cage effects.

Coating material is atomised and sprayed in the presence of an electric field created between the spray gun and a work piece of opposite polarity.

For compressed air systems, the material flow can be up to 1000 ml/min, while for airless or assisted airless techniques the material flow can be as high as 3000 ml/min.

The material efficiency of manual electrostatic spray coating is up to 85 %. Compared to conventional spray coating, electrostatic spray coating is more time and material efficient and easier to automate. There is less overspray so less waste residues are generated and spray booths require less cleaning.

For electrostatic spraying to work, the work piece has to be conductive. For this reason, it may be difficult to recoat over existing coatings. This limits the substrates the technique can be applied to.

Automatic spraying bells are most commonly used for electrostatic spray coating. They are suitable for small parts and tubular structures with only small depressions. Depending upon the size of the spraying bells, a maximum material flow rate of up to 600 ml/min is possible. Colour changes can be carried out within several seconds. The transfer efficiency is up to 95 %, but does depend on the process conditions and the geometry of the work piece.

[DFIU 2002] [BREF STS 2007] [DuPont-1 2008]

Electrostatic spraying with high rotation bells

This technique uses rotating bells for coating application. The technique can be used for both water-based and conventional materials.

It may be used for coating the interior of vehicles. It involves paint atomisation and, except in the case of the airless technique, is similar to conventional compressed air spraying. Hydrostatic pressure is used to atomise the coating material and the paint particles are then electrostatically charged (except when applying water-based coatings or when applied to plastic parts). [BREF STS 2007]

High volume low pressure spraying (HVLP)

This spraying technique is only used for manual repair applications at the end of the production line. The quality of coated surfaces may not match those achieved with high-pressure air guns because HVLP spray guns create larger particles of coating material.

For HVLP, the atomising pressure is reduced from the conventional 3 – 6 bar down to 0.7 bar. Compared to high-pressure spray coating, up to 20 % overspray can be avoided and the material efficiency ranges from 40 - 80 %. [BREF STS 2007]

Airless spraying

Airless spraying is used for coating bus and truck chassis. The technique may be used either manually or automatically. Airless spray coating gives a relatively rough finish that needs to be sanded before finer coatings can be applied - an additional process stage compared with high pressure air spraying. However, optimisation of the spraying can improve finish quality to close to that achieved with HVLP guns, especially with primer coatings.

In airless spray coating, paint is forced through very small metal nozzles (< 2 mm) at a pressure of 80 to 250 bar. The paint jet strikes the stationary air outside the nozzle and is broken into fine particles by the force of the impact of paint jet and air.

The paint is delivered to the nozzle using high-pressure pumps, this prevents fast colour changes but a high throughput of paint is possible. Airless spray coating is cheap and fast and can be used for 1-component and 2-component paint systems.

Operator training is essential in order to maximise the performance of airless spraying systems. The material efficiency for airless spray coating is about 5 % (for lattice-like working pieces) up to 40 – 75 % (for large surfaces). [BREF STS 2007]

Application of powder coatings

Powder coatings are automatically or manually applied and then melted and cured by heating the work piece. Powder systems are applicable to metal and plastic surfaces. They have been developed for filler and top coat applications. The use of reclaimed powder enables material re-use of up to 97 %. [BREF STS 2007] [BMW-1 2008] [PSA 2005]

Powder coating – electrostatically assisted spraying: The powder particles are electrostatically charged and sprayed onto the work piece using compressed air. Spray booth and application tools can be cleaned by vacuum cleaning or by blowing with compressed air. There are no solvent emissions associated with this coating technique. The material efficiency is about 80 – 95 %. [BREF STS 2007]

Powder sintering: The working piece is heated above the melting temperature of the powder coating before coatings are applied. As soon as the powder contacts the surface, sintering and merging takes place; a high material efficiency can be achieved. [BREF STS 2007]

Powder slurry: In this system powders are dispersed and stabilised in water. They are applied using conventional electrostatically assisted spray equipment for liquid paints.

Drying by combinations of infrared and air circulation techniques can reduce energy consumption. [BREF STS 2007]

4.2.2 Drying

Heated air circulating in a drier or oven is brought into direct contact with the object or surface to be dried. The drying time depends on the object or substrate, the type of coating and the coating thickness, and varies from a few seconds to a full hour.

Dehumidified air, or convection drier with an additional dehumidification step, is used for drying water-based coatings or as a pre-drying step of wet-on-wet layer constructions. By removing water in this manner the drying times can be significantly reduced. Dryer channels are designed in “A-form” to avoid heat losses (lifting the working piece through a channel designed like an A). [BREF STS 2007]

4.2.3 Cleaning

Cleaning is needed, whatever the coating application techniques, for the work pieces, the work place environment, the coating equipment and its parts.

A range of cleaning techniques can be used; most frequently these are automatic cleaning systems with solvent recovery (e.g. for spray guns).

Organic solvent cleaners are used (sometimes heated for higher efficiency) as well as water, the latter when water-based coating systems are used and if cleaning can be performed before coatings have dried.

Cleaning needs to be effective and fast. The cleaning intensity needed can vary according to the nature of colour changes to be made and depending on whether the contamination is semi-dry or dry. For semi-dry contaminations water-based systems (with tensides or with solvents) can be used. Solvents have to be used if the contamination has dried.

For colour changes, pipes can be pre-cleaned with ‘pigs’ for material recovery (plastic pieces pushed through pipes with compressed air) before cleaning is done with solvents or water (depending on the coating system).

[BREF STS 2007]

4.2.4 Cavity and transport conservation

Most manufacturers apply a wax protection layer for protection during transport. The wax can be solvent-based (70 % VOC) or water-based.

5 Solvent use, emissions and environmental impact

5.1 Solvents used

Organic solvents are used in the solvent-based coatings and the water-based coating used for vehicle coating, they are also used in solvent-based cleaners and in water-based cleaners.

Solvents are mainly mixtures of organic hydrocarbons (solvent naphtha, xylene, alcohols, esters and glycol ethers). Butyl acetate is a lead component in solvent-based base coats, which is also often used as cleaner. Alcohols, esters and glycol ethers are used in water-based coatings. Butyl Solvents with carcinogenic, mutagenic or reproductive toxicity are not used.

[DFIU 2003] [DuPont-1 2008]

Conventional solvent-based coatings

Conventional solvent-based coatings are classified as polycondensation- (e.g. phenol/urea/melamin resin), polymerisation- (e.g. polyesters-, acrylate resin-, alkyd resins) and polyaddition-laquers (e.g. epoxy or PU lacquers).

In high-solid coatings, the binders are based on epoxy resins, 2-component polyurethanes, polysiloxane, oxirane or alkyd resins.

Table 4 shows VOC contents of solvent-based coating systems.

Table 4: VOC content of conventional solvent-based coating systems

Primers	Base coats	Top coats	High-solid top coats	Clear coats
35 – 46 %	70 – 80 %	40 – 50 %	30 – 35 %	35 – 60 %

[BREF STS 2007] [DuPont-1 2008]

Water-based coatings

Water-based coatings are based on alkyd, polyester, acrylate, melamine and epoxy resins. They often contain organic solvents as a solubiliser and to improve the properties of the wet film layer.

Pre-coatings are generally water-based (for electrophoretic dipping). Primers, base coats and clear coats may also be solvent-based or powder systems. Table 5 shows VOC contents of water-based coatings.

Table 5: VOC content of water-based coating systems

Pre-coats	Primers	Base coats	Clear coats
1 - 6 vol.-%	5 – 10 vol.-%	10 – 15 vol.-%	15 vol.-%

[BREF STS 2007] [EGTEI 2003]

Powder coating

Powder systems are VOC-free. Powder slurries contain ~ 1 % VOC. [BREF STS 2007]

Cleaners

For solvent-based systems butyl acetate (100 % VOC) is the solvent used most frequently. [DuPont-1 2008]

Cleaners for water-based systems are either solvent-free or may contain up to 10 % solvents (mainly alcohols). [BREF STS 2007]

Transport conservation

Waxes are either solvent-free or may contain ~ 70 % solvents. [BREF STS 2007]

5.2 Solvent consumption and emission levels

Coating

High solid solvent-based systems for vehicle coating achieve VOC emissions of 43 – 72 g/m^2 for a primer/base coat/clear coat system, whereas conventional systems result in VOC emissions of 100 – 300 g/m^2. [BREF STS 2007]

According to the STS BREF, the use of Best Available Techniques (BAT) for vehicle coating is associated with the following emission values:

Table 6: VOC emission values associated with BAT in existing vehicle production

	Cars	**Vans, trucks**	**Truck cabins**	**Buses**
BAT associated emission values	10 – 35 g VOC/m^2	15 – 50 g VOC/m^2	10 – 55 g VOC/m^2	92 – 150 g VOC/m^2

[BREF STS 2007]

About 70 – 90 % of the total VOC emissions are emitted from the painting booths, the remaining 10 – 30 % from the drier. [BREF STS 2007]

Usually, application and drying of primer and top coat/clear coat contribute approximately 80 % of the total VOC emissions. The top coat refinishing, cleaning procedures and other sources like coating of small parts, application of underbody protection and conservation are responsible for the remaining 20 %. [BREF STS 2007]

Cleaning

If only conventional solvent-based coating systems are used, cleaners account for 15 % of the total VOC emissions from the site. If high solid systems as well as water-based primers and base coats are used cleaning with organic solvents accounts for about 20 % of total VOC emissions. It is BAT to minimise solvent emissions from cleaning to 20 g/m^2 or less. [BREF STS 2007]

5.3 Key environmental and health issues

In series coating of cars, buses, vans, trucks and truck cabins, a broad range of different solvents are used for a range of different types of processes, mainly for different coating systems and for equipment cleaning.

VOC emissions, together with NOx emissions, are precursors of ground level ozone formation in the presence of sunlight. Existing occupational workplace limits should be taken into consideration.

Emissions of VOC to air may occur from:

- the storage of the solvents,

- the process (mainly during paint application and drying),

- cleaning operations (equipment cleaning).

Spills and leaks from storage areas may result in emissions to soil and groundwater.

The process generates waste containing solvents which need to be disposed in a way that emissions to air, soil and groundwater are prevented or limited.

6 VOC Substitution

The following sections describe potential substitutes for VOC (using VOC-free and VOC-reduced systems). There are also descriptions of the application technologies or special conditions needed as well as the advantages and disadvantages compared to systems that use solvents with a high VOC content.

6.1 Powder coating systems

VOC-free powder coatings can substitute solvent-based coatings in many cases, although this is dependent on the heating of the working piece being practical and the working piece having the required surface characteristics.

Up to now only a few car producers in Europe have used the technique because powder material is more expensive and may cause quality problems. Layer thickness is greater than necessary because thin coatings are difficult to achieve yet (~ 55 - 65 µm for top coats compared with 35 – 50 µm for conventional 1-coat top coats). With powder slurries a thinner film can be achieved (~ 45 µm). [BREF STS 2007]

Initially, powder primer application in the US and in Austria (Chrysler in Graz) was considered inefficient due to material requirements and the finish quality was unsatisfactory [BREF STS 2007], but powder primer is used successfully for car coating at another site (Peugeot in Mulhouse/France) and for truck cabins without pre-coating by electrophoretic dipping (Scania in Oskarshamn/Sweden). [PSA 2005] [DuPont-1 2008]

Powder coating is also used as 1-coat top coat (Smart in Hagenau/France) and as clear coat (car coating at BMW in Dingolfing, Regensburg, Leipzig in Germany, truck chassis coating at Volvo in Gothenburg/Sweden). A parallel solvent-based clear coat line may be needed as some base coats may not be compatible with the use of the powder clear coats. [BMW-1 2008]

Powder slurry can be used as a clear coat (Daimler in Graz/Austria and Rastatt/Germany). [BREF STS 2007]

6.2 Reduction of solvent content in coating systems

The main VOC reduction possibilities, apart from changing to VOC-free powder-based systems, are to change from conventional solvent-based systems to high solid coatings, water-based systems and automatic electrostatic applications. These and other means can achieve total VOC emission reductions of about 30 – 55 %. [DFIU 2000]

High solid coatings can be used for all conventional solvent-based systems if application systems are adapted (system pressure, layer thickness).

If quality requirements allow a reduction of layers, a substantial reduction of solvent (and material) is achieved. At one site it was possible to substitute the primer by two adapted base coats that, together, have the required filler properties (‘integrated painting process’ by Mini in Oxford and VW/Seat in Martorell/Spain). [BMW-1 2008], [DuPont-1 2008]

Water-based as well as solvent-based coatings can be used on metals and plastic materials. Water-based systems cannot, however, be used with 1-coat 1-bake solid colours as they would need to be sealed with a clear coat.

Water-based primers and base coats are widely used for all types of vehicle coating.

Water-based top coats have long been used for single-layer coating of vans and driver cabins (Daimler in Düsseldorf/Germany, MAN in Munich/Germany and Steyr/Austria).

For quality reasons, in car production, water-based clear coats (with 15 % solvent content) are in use at only one site in Europe (Opel in Eisenach, Germany). [BREF STS 2007] [EGTEI 2003] Furthermore, powder slurries (water-based) are used (Daimler in Rastatt/Germany). [DuPont-1 2008]

Water-based top coats may have a poor appearance and quality due to the use of alkyd resins (also used for low quality solvent-based coatings) and poor pigment stability under UV light impact. [BREF STS 2007]

Water-based systems require stainless steel equipment and longer intermediate drying time. They require the operation of spray booths under tighter temperature and humidity controls. Drying time needs to be adjusted by heating the intermediate dryer air and by applying higher exchange rates.

Investment costs for water-based spray booths may be 10 – 20 % higher than for conventional spray booth installations. Material costs are 0 – 20 % higher compared to solvent-based coatings. Due to longer intermediate drying time the energy requirement (and related costs) for car coating with water-based systems is ~ 10 % higher than with solvent-based systems (~ 990 MJ/car instead of ~ 1100 MJ/car). [BREF STS 2007]

Switching to water-based coatings is generally combined with major plant upgrades or with new installations. In large paint shops (> 100,000 units per year) typical costs for a complete new spray booth installation are between 15 – 35 million Euro. Since 1994, most new paint shops in EU countries have been designed for water-based base coat systems.

Compared with solvent-based systems VOC reductions of 75 - 90 % are achieved with water-based systems (primers from ~ 9 to 1 g/m^2, base coats from ~ 30 to ~ 6 g/m^2 and clear coats from 13 to 3 g/m^2).

[BREF STS 2007] [DuPont-2 2008]

6.3 Substitution of VOC cleaners

VOC-free detergent systems can be used for cleaning equipment and parts when water-based coating systems are used.

The systems combine detergents with alkalis and other substances, depending on the substrates and the materials to be removed. Cleaning may take longer than with solvent-based systems.

The water-based cleaning systems may require additional heating and subsequent wastewater treatment. [BREF STS 2007]

6.4 Substitution of VOC-based conservation waxes

Solvent-based waxes can be substituted by VOC-free water-based conservation systems. [BREF STS 2007]

7 Other VOC emission prevention measures and abatement techniques

Preventive measures, process improvements and abatement techniques can be used to reduce VOC emissions if VOC substitution as described in section 6 is not possible. The following measures are commonly applied for series coating.

7.1 Process improvements

7.1.1 Improvement of application techniques

General measures to reduce VOC emissions include:

- Reducing the number of coating layers
- Applying precise contour coating
- Adjusting the width of the spray jet to the working piece's width
- Keeping the spray jet close to the coated surface
- Keeping the spray jet vertical to the surface
- Keeping air pressure as low as possible, but adequate for quality requirements

[BayLFU 2005]

VOC emissions can be reduced by replacing application techniques with more efficient techniques (see table 3 below).

Table 7: Efficiency of application techniques

Efficiency of application techniques				
Method	**Degree of efficiency**	**Suitable coating system**	**Geometry of the work piece**	**Other restrictions**
Dipping	75 – 90 %	1-component systems	Non-scooping parts	High solvent loss
Electrostatic assisted compressed air spraying	50 – 80 %	1- and 2-component systems	No Faraday cage	Electrically conducting materials are necessary
Compressed air spraying	20 – 65 %	1- and 2-component systems	No limitation	-
Airless	40 – 80 %	1- and 2-component systems	Big, simple	-
HVLP	45 – 65 %	1- and 2-component systems	No limitation	-
Powder with electrostatic spray technique	50 – 95 %	Powder	No limitation	Electrically conducting temperature resistant materials are necessary

[DFIU 2003]

7.1.2 Reduction of VOC emissions from cleaning

To reduce the solvents used for cleaning and thus the resulting emissions, the following measures can be applied: [BayLFU 2005] [DFIU 2000] [BREF STS]

- Using cleaning solvent as sparingly as possible
- No cleaning of equipment for base coatings or coatings with low optical requirements
- Consecutive coating of same coloured working pieces
- Use of the pig-clearing method[5] to avoid residues remaining in pipes
- Immediate cleaning of parts, leaks, spillages and working environment before coating materials dry

[5] ‘pigs’ are plastic pieces, forced with compressed air through pipes to transport coating remains left over in pipes back to the storage tank. The system is only applicable, where paints are delivered to machinery through pipes and different colours are sent through the same pipe regularly.

- Use of systems that allow back-flow of solvents into a closed container. Cleaners are pumped through a tap or sprayed onto the object in a partially enclosed work area above the storage drum. The work area allows flow back of surplus solvents through coarse filters into the drum.

- Regular inspections of storage areas and working environment to ensure appropriate handling of cleaning solvents.

- Minimising exposure of the open surface of liquid solvent in the working station.

- Use of cartridge systems for exact dosing of coating material to avoid contamination of pipes during colour changes.

- Automatic equipment washing can be combined with re-use systems that achieve up to 80 – 90 % solvent recovery. Problems may occur with 2-component clear coat materials, which can lead to clogging of recovery tank pipes. A solvent recovery system costs 0.4 million € per spray booth. [BREF STS 2007]

7.2 Abatement technologies

If primary measures are not sufficient to meet the emission limit values or cannot be applied, VOC emissions can be destroyed by thermal oxidation.

For series coating, abatement technologies are applied to treat exhaust air from dryers after solvent-based as well as after water-based systems. Thermal oxidation is commonly used. After solvent-based clear coating it can be combined with heat recovery for pre-heating of drier air.

Thermal treatment of waste gas is also necessary when water-based primers or base coats are applied. It is less effective, as together with VOC emissions high volumes of clean air are extracted. In these cases adsorption (on zeolite) and concentration may be used to achieve VOC concentrations that do not require the use of additional natural gas to maintain the oxidising flame.

8 Summary of VOC emission reduction measures

Table 8 summarizes the VOC emission reduction measures presented in chapters 6 and 7:

Table 8: Measures for VOC substitution and VOC reduction in vehicle coating and vehicle refinishing

Objectives	**Description**	
Substitution/ Solvent free processes	Substitution of VOC by change of application systems	Use of powder coatings
	Substitution of VOC cleaners	Use of VOC-free cleaners e.g. water-based cleaners (with detergents) for cleaning of equipment, parts and booth
Substitution / Reduction of the solvent content	Reduction of the solvent content in coating systems	Change from conventional coating systems to high solid solvent-based systems or to water-based coating systems
Process Improvements	Improvement of application techniques	Reduction of the number of coating layers Optimisation of spraying technique (increase of automation and electrostatic applications)
	Reduction of cleaning effort	Reduction of colour changes. Immediate cleaning before drying. Recover cleaner and minimise use. Emptying of pipes by ‘pig’ systems before cleaning. No cleaning for application of base coats or coats with low optical requirements. Consecutive coating of same coloured working pieces. Use of cartridge systems for optimised material dosing.
Abatement Technologies	Concentration of VOC (before abatement)	Zeolite adsorption wheel
	Destruction of VOC	Thermal oxidation (with heat recovery)

9 Good practice examples

Application of VOC-free powder coating technology has been introduced by BMW, initially in the Dingolfing/Germany plant and later also in its plants in Leipzig/Germany and Regensburg/Germany. Before its introduction coating each car body used about 1 kg of solvent. The amount of solvent substituted, at a typical daily production of up to 1200 car bodies, is approximately 400 tonnes per year.

Robots open and close the vehicle doors automatically. Coating of the doors and the rear of the car is done by using ‘line-tracking’ (robot follows a specific line on the body surface). The remaining surfaces are coated by static coating machines. An electrode in the rotation atomiser electrically charges the clear-coat powder as it is sprayed – the powder particles then adhere to the grounded car-body. Later, in the dryer, the powder melts at about 145°C, becoming transparent and fusing with the coloured water-based base-coat.

The powder-coating technology used delivers both ecological advantages and a technically improved product. The automated process produces neither coating sludge nor waste water. The combination of new coating techniques and robotics guarantees high cost effectiveness. The clear-coat powder not fixed on the surface (the overspray) is collected and mixed with new powder for re-use. The new process is not only VOC-free but has also reduced the total waste of the coating installation by about 50 %.

[BMW-2 2008]

10 Emerging techniques and substitutes under development

Water-based top coats with less than 10 % solvent content (instead of less than 20 %) are under development and are expected to be employed in 2011 in the Hyundai paint shop in Ostrava/Czech Republic [Hyundai 2008].

First applications of very high solid base coats (50 – 60 % solvent content) have been realised (Ford in Genk/Belgium) [DuPont-1 2008].

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