METI (Ministry of Economy, Trade and Industry)Project

Development of a Risk Trade-off Analysis Method for Optimal Management of Chemicals

EMISSION SCENARIO DOCUMENT

－SOLVENTS FOR INDUSTRIAL COATINGS－

October　2012

The Research Institute of Science for Safety and Sustainability

Independent Administrative Institution

National Institute of Advanced Industrial Science and Technology

About the Emissions Scenario Document

This document was written as part of the "Development of a Risk Trade-Off Analysis Method for Optimal Management of Chemicals" project. The National Institute of Advanced Industrial Science and Technology was commissioned by the Ministry of Economy, Trade and Industry to run the project.

"Development of a Risk Trade-Off Analysis Method for Optimal Management of Chemicals" focuses on the trade-off of risks faced when one chemical is substituted for another for various reasons. Material substitution is effective in reducing the risks inherent in the material to be replaced. However, selecting and substituting one material for another, if not done carefully, can introduce new risks. In some cases, the risk reduction afforded by the substitution is negated because of new risks introduced by the new material. In other cases, the risk may in fact increase because of the substitution. Therefore, in the risk-based management of chemical substances, to verify the overall risks before and after substitution it is important to evaluate the risks associated with the *material to be replaced* in conjunction with the risks associated with the *material that will replace it*.

Generally, a substance for which there is abundant assessment information on exposure and toxicity risks is replaced by a new material with limited information. Hence, we are developing a risk trade-off analysis method that, from a limited amount of information, can quantitatively estimate the exposure risks posed by the new material.

An emission scenario document is a document that shows the sources, manufacturing process, transportation paths, and typical uses of a chemical substance in order to quantify emissions of the chemical into environmental media. This document was created to provide data on various parameters, along with a method of estimating the environmental emissions of chemicals used as substitutes for other materials in industrial coatings even when there are insufficient data.

We hope that this document will be useful in a wide range of fields.

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EXPLANATORY NOTES

Purpose and background

This OECD Emission Scenario Document (ESD) is intended to provide information on the sources, use pattern and release pathways of chemicals used in solvents for industrial coatings, so as to help estimating the amount of chemicals released into the environment.

This ESD should be seen as a living document, that provides the most updated information available. As such, the ESD can be updated to take account of changes and new information. If can aiso be, extended to cover industries in countries other than the lead country,i.e. Japan. Users of the document are encouraged to submit comments, corrections, updates and new information to the OECD's Environment, Health and Safety Division (env.riskassessment@oecd.org). The comments received will be forwarded to the lead country so that it can update the document. The comments will also be made available to users within the OECD web-site (www.oecd.org/env/riskassessment).

This OECD Emission Scenario Document (ESD) is intended as a document to complement the method used in the "*OECD Series on Emission Scenario Documents No. 22 Emission Scenario Document On Coating Industry (Paints, Lacquers and Varnishes)"* (hereafter OECD,2009).

How to use this document

The user of this ESD needs to consider how the information it contains covers the situation for which they wish to estimate releases of chemicals. The document can be used as a framework to identify the information needed, or alternatively the approaches in the document can be used together with the suggested default values to provide estimates. Where specific information is available it should be used in preference to the defaults. At all times, the values inputted and the results should be critically reviewed to assure their validity and appropriateness.

How this document was developed

This ESD was produced mainly on the basis of Japanese data. In Japan,this ESD was created as a part of a NEDO (New Energy and Industrial Technology Development Organization) project entitled Development of Methodologies for Risk Trade-off Analysis towards Optimum Chemical Substance Management (2007–2011) (hereinafter referred to as the RTA project). The RTA project focuses on the trade-off of risks faced when one chemical is substituted for another for various reasons. Material substitution can be effective in reducing the risks inherent in the material to be replaced. However, selecting and substituting one material for another, if not done carefully, can introduce new risks. In some cases, the risk reduction afforded by the substitution is negated by new risks introduced by the new material. In other cases, the risk may in fact increase because of the substitution.

This ESD aims to provide a method of estimating emission quantity in the absence of sufficient empirical data to support an analysis of the substitution of one industrial cleaner for another. It also aims to provide data on each parameter. Among scenarios that are highly likely to occur (as determined by analyzing trends in the substitution of cleaning chemicals), we focus on possible combinations of currently used substances and their substitutes. We also examine changes in operating conditions and cleaning equipment due to the use of substitute materials.

Coverage

This ESD is intended to estimate the volumes of solvent substances (VOCs) and their emissions to the air from industrial coatting processes. General information on coatings and coating processes is already given in detail in the OECD (2009) and is therefore not covered in this ESD.

The following processes that are included in the OECD (2009) estimation are not within the scope of this ESD: mixing and color matching processes of coatings before the coatings application process; disposal processes of coatings; and cleaning processes of coating equipment.

The scope of this ESD is the OECD's IC 14 "Paints, lacquers, and varnishes"; the use category is equivalent to UC 48, "Solvents." The scope in terms of lifecycle stage is roughly equivalent to the industrial application stage of coatings.

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1. Introduction

1.1 General introduction

This Emission Scenario Document (ESD) describes a method for estimating the amounts of volatile organic compounds (VOCs) used and emitted into the air during the coating process in industrial applications. This Chapter first gives an overview of existing ESDs and relevant documents. It then overviews the statistical data on the use of coatings in Japan according to the types of coatings used and their VOC components, as well as the trends in the types of coatings used in various industries. Lastly, we explain the features of this ESD, its scope, and its position in relation to existing documents.

1.2 Overview of existing Emission Scenario Documents

This Section gives an overview of the following existing documents concerned with the estimation of VOC emissions from coatings: the *OECD Emission Scenario Document* (OECD, 2009) and the *Report on Volatile Organic Compound (VOC) Emission Inventory* (Ministry of the Environment, 2010).

1.2.1 OECD Emission Scenario Document

The *OECD Series on Emission Scenario Documents No. 22 Emission Scenario Document On Coating Industry (Paints, Lacquers and Varnishes)* (OECD, 2009) is an ESD for the estimation of emissions from coatings. The industrial category (IC) covered in this ESD is IC 14, “Paints, lacquers and varnishes.” The use categories (UCs) covered in the OECD document are wide ranging (see Table 1.1). In this present ESD, the VOCs included in the emission estimation are assumed to be equivalent to the solvent components in Table 1.1. Thus, in the descriptions of the emission estimation method introduced in this ESD, the solvent components in coatings will be referred to as VOCs.

Table 1.1 Use categories of coating components covered in the OECD (2009) emission scenario document

Component	Use category (UC)	Description
Main use categories		
Binders	2	Adhesive and binding agents
Pigments and dyes	10	Coloring agents
Solvents	48	Solvents
Fillers	20	Fillers
Additives in smaller quantities		
Anti-skinning agents, rheology modifiers	52	Viscosity adjusters
Biocides	37	Biocides, non-agricultural
Catalysts, defoamers	43	Process regulators
Dispersants, surfactants	50	Surface-active agents
Flame retardants	22	Flame retardants and fire-protection agents

Flattening agents	0	Other
Plasticizers	47	Softeners

Source: OECD (2009)

The OECD (2009) ESD is composed of four parts, Parts I to IV (Table 1.2) and provides comprehensive emission estimations for each lifecycle stage of coatings. Part I gives a general information on coatings and describes such characteristics as the formation and structure of a coating film, the constituents of a coating, the life cycle, legislative regulations, and market trends. Part II explains items that are relevant to the estimation of emissions from the manufacturing stage of various coatings, which are roughly categorized into organic solvent-borne, waterborne, and powder coatings. By referring to various products as examples, Part III provides emission estimations for each of the following stages: industrial application of coating (coating process), service life of coated products, and recycling and disposal of coated products.

Table 1.2 Overview of the structure of the OECD ESD (2009)

	Overview	Main contents	Lifecycle stage
Part I	General information on various coatings	・Basic information on constituents, components, structure of a coating film, life cycle, legislation, classification of coatings, etc. ・Information on the European coatings industry: sales of coatings in the EU, ratio of each type of coating sold, and trends in powder coatings	
Part II	Estimation of emissions from the coating manufacturing process	・Overview of the coating manufacturing process and related processes, and of emission prevention and abatement techniques ・Methods for estimating emissions from the manufacture of various organic solvent-borne, waterborne, and powder coatings into air, water, soil, and waste, and examples of emission calculations	Manufacture and processing
Part III	Estimation of emissions from the coating process, as well as from use and disposal of coated products	・Overview of the coating process and methods of emission estimation ・Methods for estimating emissions from the various stages of the coating process, the use of coated products, and the recycling and disposal of coated products. Calculation examples are given for the following products: wooden furniture, decorative paints, automobiles, metal packaging,steel coils, ships, aircraft, and rail vehicles	Industrial application, service life, recycling, and disposal
Part IV	Glossary and references		

Source: Based on OECD (2009)

The basic method used to estimate emissions during the coating manufacturing stage, as described in Part II of the OECD ESD (2009), is to multiply three parameters, namely the volume of coatings manufactured (weight per year or per day), the percentage of target components (weight/weight), and the emission rate (%). The method for estimating emissions from each of the products listed in Part III widely incorporates the emissions from each of the three stages, namely the industrial application of coatings (coating process), the service life of each product, and the recycling and disposal of coated products, to derive total emissions. The components of coatings are roughly classified into solid and volatile; by assuming the initial volume of each to be 100%, emissions are estimated by taking into consideration the rates of loss to the air, water, land, and disposal in the stages of initial coating, coated product, and end-of-life. The parameters used for estimating emissions in Part II and Part III are derived by using the method described in the OECD document; representative values or values deduced from reference materials are used, or otherwise values are assumed on the basis of individual cases.

1.2.2 VOC inventory

To understand the present status of the development of VOC emission reduction measures, the Ministry of the Environment of Japan established a VOC Emission Inventory Study Group in FY 2006 and surveyed the VOC emissions from various sources to create a VOC inventory. The Study Group has estimated the VOC emissions for the base year of FY 2000 and every year since FY 2005. In the report by the Ministry of the Environment (2010) on the VOC emission inventory, estimated amounts of VOC emissions are provided for 34 types of emission sources, classified by their use purpose in each emission stage, namely manufacture, storage and shipment, application (solvents), and application (other than solvents). For coatings, VOC emissions are estimated for source items that emit VOCs while being used as solvents (mixtures) in the application (solvent) stage of emissions.

The report by the Ministry of the Environment (2010) covers 27 industry sectors (including the transportation machinery and transportation equipment manufacturing industry, the construction industry, and the metal product manufacturing industry) and 11 substances (including xylene and toluene) in its estimation of VOC emissions from the application of coatings. Figure 1.1 is a flow diagram describing the steps in estimating VOC emissions. The values for three items, namely “Sales of each type of coating per demand sector,” “Ratio of each solvent component per coating type,” and “Rate of dilution of each type of coating with each solvent,” are used as bases for calculating the “Use of each VOC per demand sector.” The values for the above three items and for the “Air emission rate per demand sector” are derived from research conducted by an incorporated body, the Japan Paint Manufacturers Association. The “Emission of each VOC per industry” that is obtained as a result of the estimations is the product of adjustments made to the “Emission of each VOC per demand sector” by using the “Composition ratio of VOC emissions per industry sector and per demand sector,” which is created on the basis of the inter-industry relations table created by the Ministry of Economy, Trade and Industry.

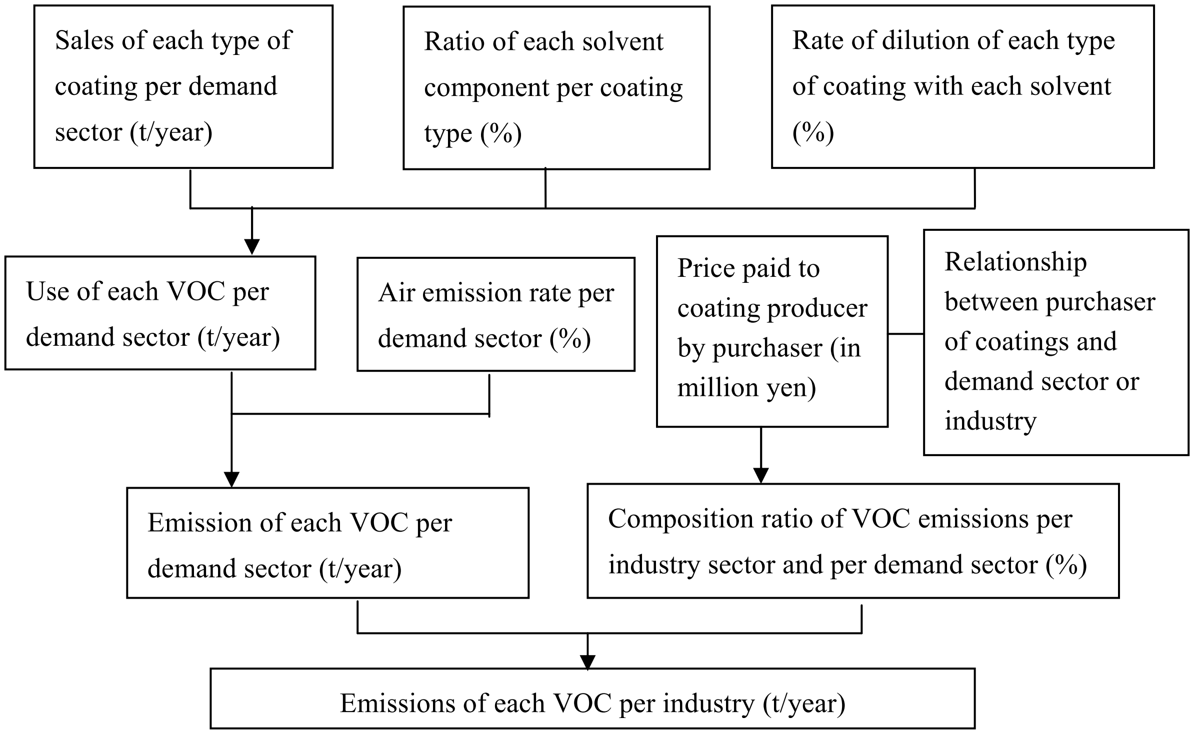

Figure 1.1 Flow diagram for estimating emissions in the Ministry of the Environment's VOC Inventory

Source: Extracted from Ministry of the Environment (2010)

1.3 Situation surrounding the use of coatings in Japan

In this Section, data compiled by the Japan Paint Manufacturers Association on the total sales of coatings in Japan, the ratios of solvent components in coatings, and the rates of dilution with thinner per industry sector, all of which are compiled per coating item and per fiscal year, will be used to describe the characteristics of sales per coating type, the ratio of solvent to coating, and the ratio of sales per coating type per industry. The data will also be used to examine the relationship between the use situation of coatings and the sources of VOC emissions.

The details of the coating types covered in this ESD are shown in the next Chapter in Table 2.1.

1.3.1 Trends in annual sales of coatings

To understand the trend in the sales of coatings in Japan, sales of each type of coating are shown in Figure 1.2 and sales of coatings per industry are shown in Figure 1.3; both figures are based on data from the Japan Paint Manufacturers Association (2003, 2007, and 2010).

Sales of solvent-borne and water-borne coatings in FY 2005 and FY 2008 were lower than those in FY 2000. However, within the solvent-borne coatings, coatings classified as high-solids types showed an increase in sales. The industry with the largest sales in FY 2008 was the building industry, followed by the automobile, shipbuilding, and metal products industries.

The decrease in the use of coatings was likely caused by such factors as a decrease in the production of coated products; a decrease in area coated; a decrease in coating losses owing to process improvements; and an increase in the ratio of solid components (i.e. the components that create coating films) in coatings.

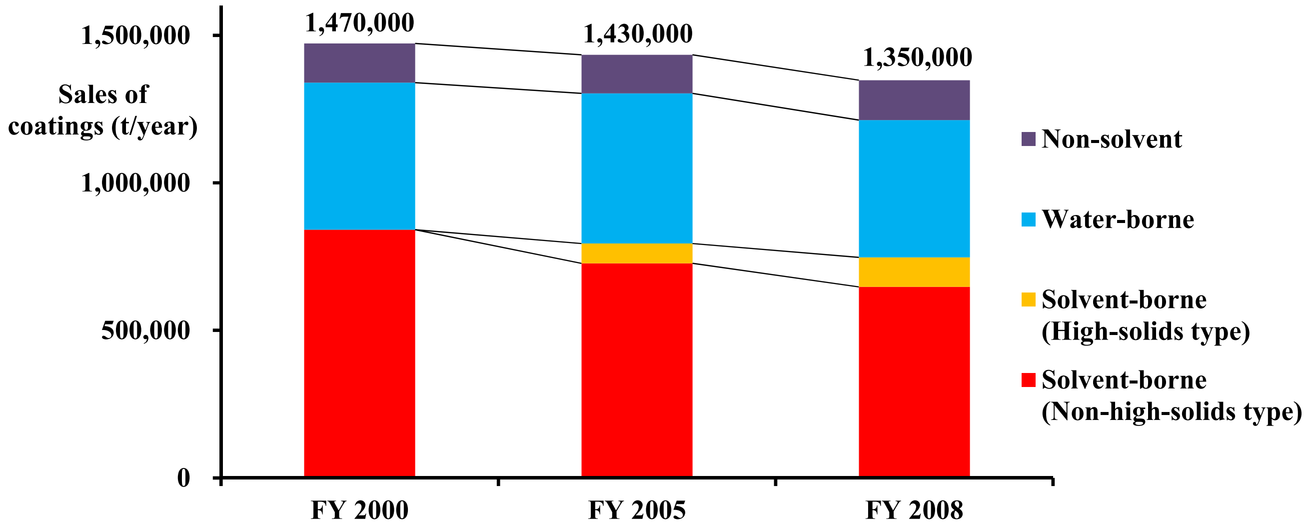

Figure 1.2 Sales of each type of coating in FY 2000, 2005, and 2008

Source: Based on Japan Paint Manufacturers Association (2003, 2007, and 2010)

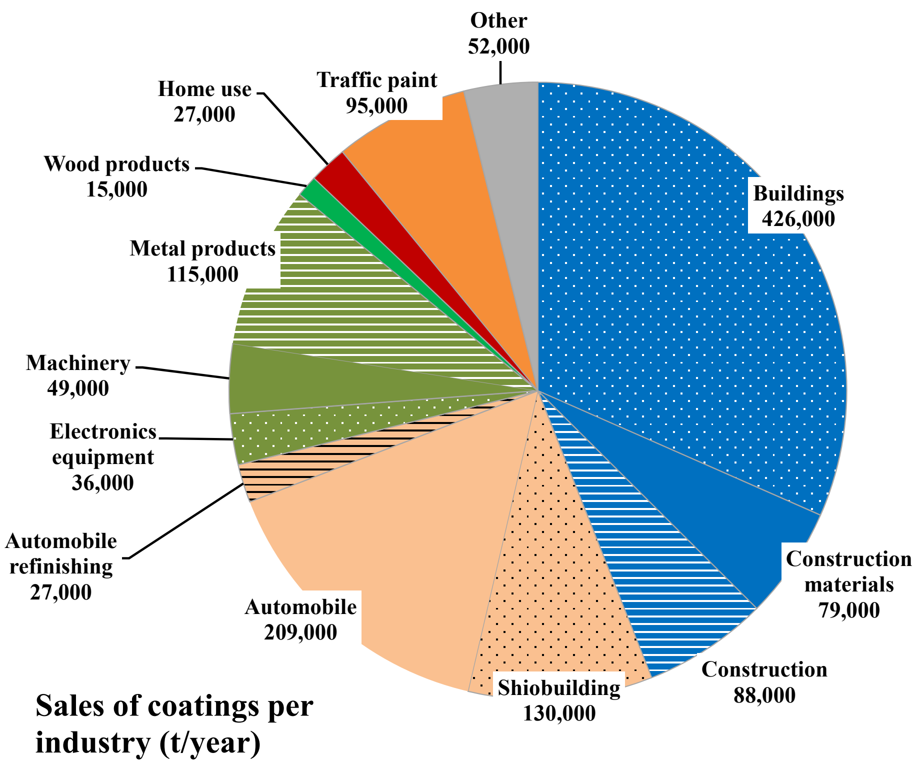

Figure 1.3 Sales of coatings per industry (FY 2008)

Source: Japan Paint Manufacturers Association (2010)

1.3.2 Composition ratios of sales of coatings of each type per industry

To understand the types of coatings sold in Japan and primarily used by each industry, the ratios of sales of each type of coating when the total sales volume of coatings for the said industry is assumed to be 100% are shown in Figure 1.4. This information is based on that from the Japan Paint Manufacturers Association (2010).

Figure 1.4 reveals that the industry sectors of wood products, automobile refinishing, machinery products, and metal products have high sales rates for solvent-borne coatings; the building and construction materials sectors have high sales of water-borne coatings; and the traffic paint sector has a high sales rate of non-solvent coatings. The figure also shows that the new automobile sector has approximately the same sales ratios for solvent-borne and water-borne coatings. In the shipbuilding and construction sectors, the sales ratios for water-borne coatings are small and the sales ratios for solvent-borne high-solids types are comparatively large.

Thus each industry sector is characterized by particular ratios of sales per coating type. This is likely due to differences in the coating functions and performances required by each industry sector; in the objects to be coated; and in the coating processes.

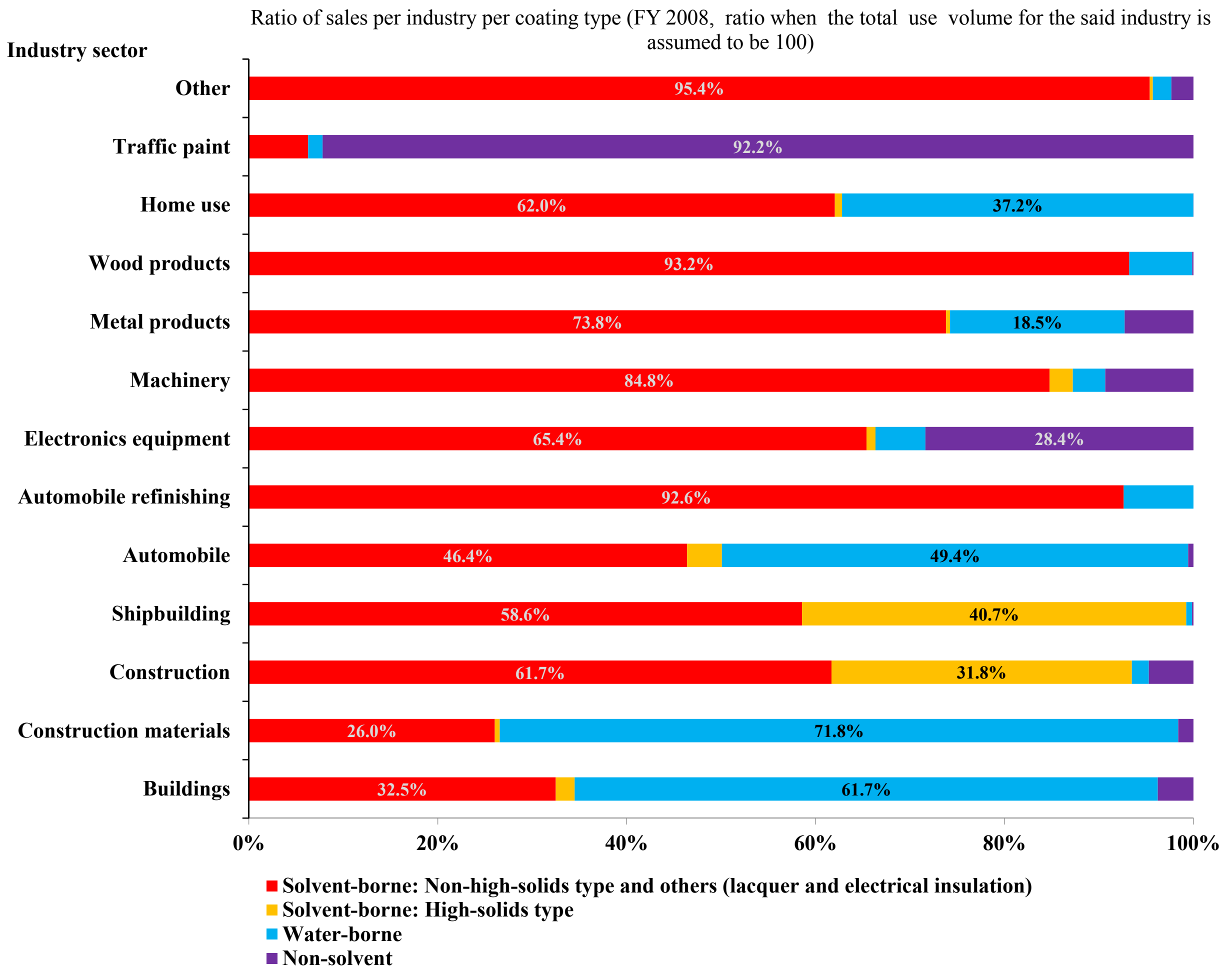

Figure1.4 Ratios of sales of each type of coating per industry

Source: Based on Japan Paint Manufacturers Association (2010)

1.3.3 Ratios of VOCs in diluted coatings

As will be explained in Chapter 2, in the estimation in this ESD of VOC emissions from coating processes, the volume of VOCs used in the coating process is calculated as a way of estimating emissions. The VOCs used in the coating process originate from the solvents contained in the coatings and the solvents used to dilute the coatings. For this reason, in estimating VOC emissions, comprehension of the ratios of VOCs in the diluted coatings used in the coating process is crucial. In Figure 1.5, the ratios of VOCs in each type of coating are shown to illustrate the current status of VOC use in diluted coatings in Japan.

The ratios of VOCs shown in Figure 1.5 are calculated by using data from the Japan Paint Manufacturers Association (2003 and 2010) on the ratios of solvent components and thinner dilution rates per industry sector and per coating item. The ratios were derived by dividing the sum of the amount of solvent component in a certain type of coating and the amount of the diluting solvent by the total sales volume of coatings.

As shown in Figure 1.5, different trends clearly exist for solvent-borne coatings (data for FY 2008 include those for high-solids types) and water-borne coatings in terms of the ratio of VOCs in the diluted coatings. Therefore, there is a close connection between the use of a certain type of coating and the ratio of VOCs in the diluted coating.

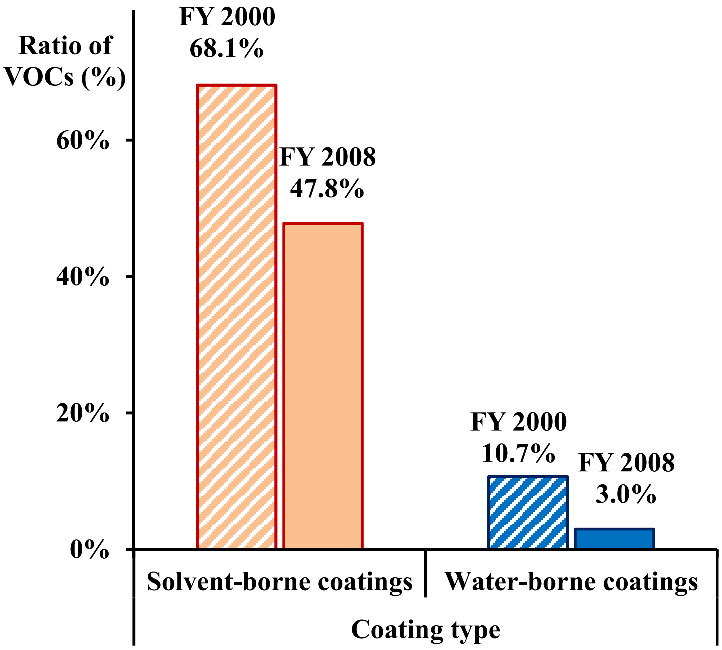

Figure 1.5 Ratios of VOCs in different types of coatings

Source: Based on Japan Paint Manufacturers Association (2003 and 2010)

1.4 Features and scope of this ESD and its relationship to existing documents

Because VOCs emitted from the coating process originate from solvents used in conjunction with the coatings, in this ESD the amounts of VOCs used will also be estimated in the process of estimating the

VOC emissions arising from the coating process. The notion behind this is that the amounts of VOCs used can be estimated in relation to coating type, and the coating type can be inferred from the industry sector.

The two existing emission estimation methods briefly reviewed in Section 1.2 both arrive at the amount of VOCs used in a target substance by multiplying the ratio of components in the coatings of the target substance by the volume of coatings; the volume of coatings itself is assumed to be a given value based on past records. In contrast, in this ESD we aimed to develop a method by which the volume of coatings is estimated first and is then used to estimate the amounts of VOCs used and the VOC emissions. In summary, this ESD provides a mathematical formula that can be used to obtain simultaneous estimations of the amounts of VOCs used and emitted from the use of coatings even when the volume of coatings is not known; a representative parameter value estimated from known information on an industry sector is applied to an emission estimation formula.

This ESD is intended as a document to complement the method used in the OECD's ESD (OECD, 2009; see Section 1.2.1) to estimate the volumes of solvent substances (VOCs) and their emissions to the air from industrial coating processes. General information on coatings and coating processes is already given in detail in the OECD ESD (2009) and is therefore not covered in this ESD.

The scope of this ESD is the OECD's IC 14 "Paints, lacquers, and varnishes"; the use category is equivalent to UC 48, "Solvents." The scope in terms of lifecycle stage is roughly equivalent to the industrial application stage of coatings.

Although the industry sectors covered in this ESD differ from the OECD's industrial category, they focus on those that use industrial coatings (i.e. coatings applied in factories), including the automobile, metal products, wood products, machinery manufacture, shipbuilding, and other industries. However, industry sectors such as building and construction, which mostly apply coatings outdoors, can also be subjected to these estimations if it is assumed that the total amount of VOCs applied is emitted to the environment.

Note that, as shown in Figure 2.1 in Section 2, only those industrial coating processes that are thought to be major sources of VOC emissions—namely, processes that start with the actual application of coatings and extend to their drying—are covered in the emission estimations in this ESD. As a result, the following processes that are included in the OECD (2009) estimation are not within the scope of this ESD: mixing and tinting of coatings before the application process; disposal of coatings that remain in containers and become coating waste; and emissions from thinners used for such purposes as cleaning.

2. Creation of a mathematical formula to estimate the amounts of VOCs used and emitted

The classification of coatings covered in this ESD is shown in Table 2.1. In this ESD, coating items listed in the classification of coatings as defined by the Japan Paint Manufacturers Association (2010) are roughly categorized into “solvent-borne” coatings and “water-borne” coatings according to the components in the coatings. Among the synthetic resin coatings, those that are solvent-borne, lacquers, electrical insulating coatings, and of various other types are classified into the “solvent-borne” category. Those that are water-borne are classified into the “water-borne” category. As shown in Table 2.1, the Japan Paint Manufacturers Association classifies four items of the solvent-borne type that have a high content of non-volatile components as “high-solids type.” In this ESD, these four items are treated as solvent-borne (high-solids type) (see Section 1.3).

Table 2.1 Classification of coatings covered in this ESD

<table>
<tr><th colspan="4">Classification of coatings by the Japan Paint Manufacturers Association</th><th>Classification of coating types in this ESD</th></tr>
<tr><td colspan="4">Lacquers</td><td rowspan="5">Solvent-borne type</td></tr>
<tr><td colspan="4">Electrical insulating coatings</td></tr>
<tr><td rowspan="18">Synthetic resin coating</td><td rowspan="18">Solvent-borne type</td><td rowspan="4">Alkyd resin systems</td><td>Varnishes and enamels</td></tr>
<tr><td>Ready-mixed paints</td></tr>
<tr><td>Anticorrosive paints</td></tr>
<tr><td>Anticorrosive paints (high-solids)</td><td>Solvent-borne type (high-solids type)</td></tr>
<tr><td colspan="2">Amino-alkyd resin systems</td><td rowspan="3">Solvent-borne type</td></tr>
<tr><td rowspan="3">Acrylic resin systems</td><td>Air-drying type</td></tr>
<tr><td>Baking type</td></tr>
<tr><td>Baking type (high-solids)</td><td>Solvent-borne type (high-solids type)</td></tr>
<tr><td rowspan="2">Epoxy resin systems</td><td>General type</td><td>Solvent-borne type</td></tr>
<tr><td>High-solids type</td><td>Solvent-borne type (high-solids type)</td></tr>
<tr><td colspan="2">Urethane resin systems</td><td rowspan="3">Solvent-borne type</td></tr>
<tr><td colspan="2">Unsaturated polyester resin systems</td></tr>
<tr><td rowspan="2">Anti-fouling paints</td><td>General type</td></tr>
<tr><td>High-solids type</td><td>Solvent-borne type (high-solids type)</td></tr>
<tr><td rowspan="4">Other solvent systems</td><td>Vinyl resin systems</td><td rowspan="4">Solvent-borne type</td></tr>
<tr><td>Chlorinated rubber systems</td></tr>
<tr><td>Silicone and fluorocarbon resin systems</td></tr>
<tr><td>Other</td></tr>
</table>

	Water-borne type	Emulsion paints	Water-borne type
		Thick-film emulsion coatings	
		Water-based resin coatings	
	Non-solvent type	Powder coatings	Non-solvent type
		Traffic paints	
		Solvent-free epoxy resin coatings	
		Solvent-free urethane resin coatings	
Other coatings			Solvent-borne type

Extracted from Japan Paint Manufacturers Association (2010)

Figure 2.1 shows a typical industrial coating process in a factory. The figure is based on the concept for calculating emissions and others as described by the Japan Chemical Industry Association et al. (2001). In this ESD, the formula for estimating the VOC contents of coatings and the amounts emitted to air is constructed on the basis of the process assumed and illustrated in Figure 2.1. The parameters for the formula are shown in Table 2.2.

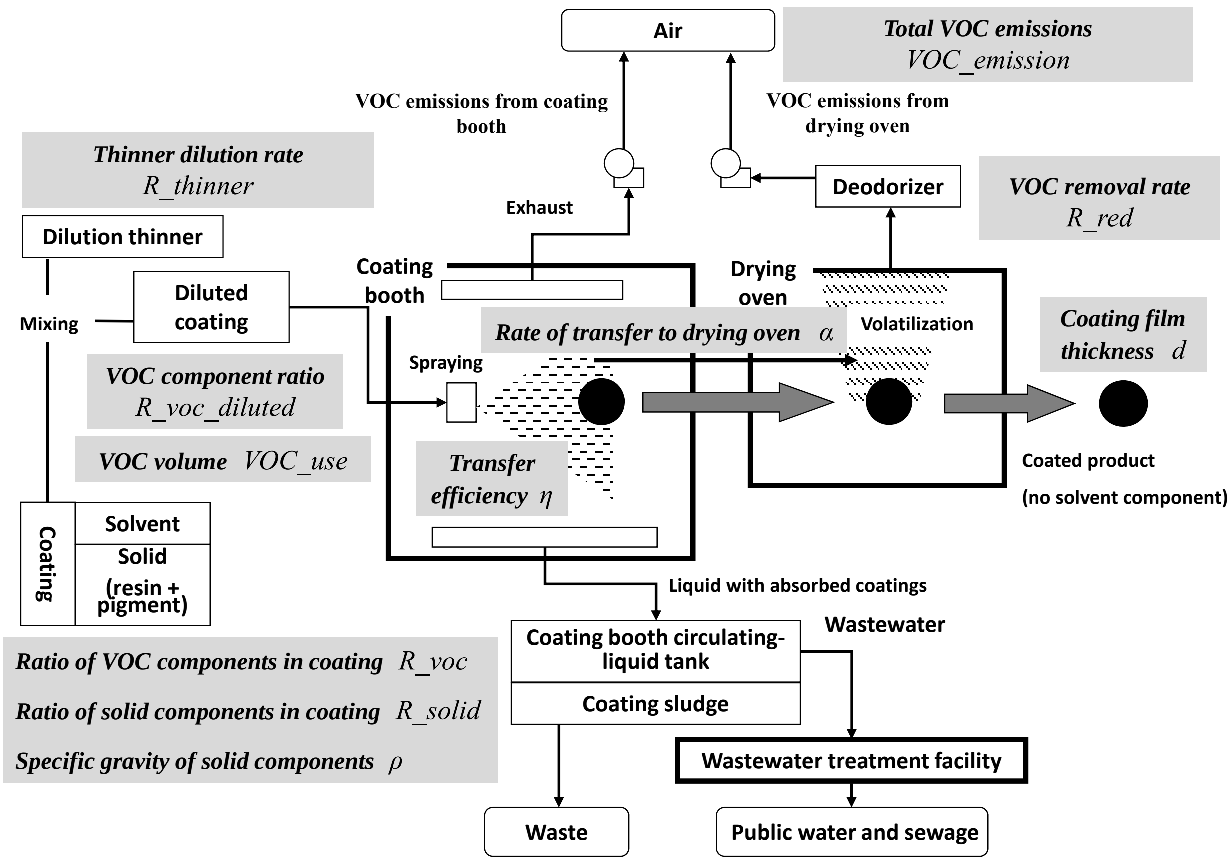

Figure 2.1 Assumed coating process and major variables

Table 2.2 Coating process parameters used in the formula used to estimate VOC volumes used and amounts emitted

Symbol	Meaning	Unit
Input parameter		
d	Coating film thickness	μm
ρ	Specific gravity of solid component	g/cm^3
η	Transfer efficiency	―
α	Rate of transfer to drying oven	―
R_{voc}	Weight ratio of VOC components in coating	%
R_{solid}	Weight ratio of solid components in coating	%
$R_{\_thinner}$	Thinner dilution rate (weight ratio of thinner to coating)	%
$R_{\_red}$	Rate of VOC removal by deodorizer	―
Output parameter		
$R_{solid\_diluted}$	Weight ratio of solid components in diluted coating	%
$R_{voc\_diluted}$	Weight ratio of VOC components in diluted coating	%
VOC_{use}	Amount of VOCs used per unit area coated	g/m^2
$VOC_{emission}$	VOC emissions per unit area coated	g/m^2

2.1 Composition and dilution of coatings

It is assumed that an undiluted coating (hereinafter referred to as a "coating") is diluted with thinners and used as a diluted coating. The components of a coating are roughly divided into three: the VOC component, the solid component, and water. It is assumed that VOCs are used as thinners for solvent-borne coatings; for water-borne coatings, water is used. The relationship between the ratio of solid components in the diluted coating, the weight ratio of solid components in the coating, and the thinner dilution rate can be estimated by using the following formula:

$$R_{\_solid\_diluted} = \frac{R_{\_solid}}{100 + R_{\_thinner}} \times 100 \qquad (1)$$

The relationship between the weight ratio of VOC components in the diluted coating, the weight ratio of VOC components in the coating, and the thinner dilution rate can be estimated by using the following formula, separately for solvent-borne and water-borne coatings:

＜Solvent-borne coatings＞

$$R_{\_voc\_diluted} = \frac{R_{\_voc} + R_{\_thinner}}{100 + R_{\_thinner}} \times 100 \qquad (2)$$

＜Water-borne coatings＞

$$R_{\_voc\_diluted} = \frac{R_{\_voc}}{100 + R_{\_thinner}} \times 100 \tag{3}$$

The symbols used in each parameter are defined in Table 2.2. In reality, a certain amount of coating remains in the containers used and in other processing components. These lost coatings become waste coatings, but because their amount is minimal they are omitted from the estimation formula.

2.2 Estimation of amounts of VOCs used

It is assumed that when a diluted coating is sprayed onto an object to be coated, the solid component is either attached to the object to be coated or is not attached to the object and becomes a coating sludge. If we assume that, of the solid component in a diluted coating, the proportion that is attached to the object to be coated is defined as the transfer efficiency (η: dimensionless) and the attached solid component forms a film with a thickness of d (μm) on the surface of the coated object, then we can estimate the amount of VOC use ($VOC_{\_use}$) in the applied diluted coating per unit of coated area by using the following formulae for solvent-borne and water-borne coatings:

＜Solvent-borne coatings＞

$$VOC_{\_use} = d \times \rho \times \frac{1}{\eta} \times \frac{R_{\_voc} + R_{\_thinner}}{R_{\_solid}} \tag{4}$$

＜Water-borne coatings＞

$$VOC_{\_use} = d \times \rho \times \frac{1}{\eta} \times \frac{R_{\_voc}}{R_{\_solid}} \tag{5}$$

2.3 Estimation of VOC emissions from a coating booth and drying oven

Because coating booths generally use large amounts of forced air and are low in VOC concentration, exhaust-gas treatment equipment is normally not installed; for this reason, it is assumed that all VOCs evaporated inside a coating booth are emitted into the air. It is also assumed that the VOC components contained in the coating and attached to the coated object can be divided into those that will be transferred to the drying oven still attached to the coated object and those that are not transferred to the drying oven but remain in the coating booth and evaporate inside the booth. For the VOC components contained in the coating and attached to the coated object, the proportion that is transferred to the drying oven is defined as the "rate of transfer to the drying oven (α)."

The VOC component that is contained in the coating sludge (i.e. the solid component that is not attached to the object to be coated) and is transferred to the environment outside the coating booth is considered to be negligibly small and thus is not included in the estimation formula.

For VOCs that are transferred into the drying oven attached to the coated object, the removal rate is $R_{\_red}$ in the case where exhaust-gas treatment equipment is installed. When exhaust-gas treatment equipment is not installed, it is assumed that the VOCs are all emitted into the air.

Under these assumptions, the VOC emission ($VOC_{\_emission}$) per unit of coated area into the air from a coating booth and a drying oven in the case of solvent-borne or water-borne coatings can be estimated by using the following formulas:

＜For Solvent-borne coatings＞

$$VOC_{\_emission} = d \times \rho \times \frac{1}{\eta} \times \frac{R_{\_voc} + R_{\_thinner}}{R_{\_solid}} \times (1 - \eta \times \alpha \times R_{\_red}) \quad (6)$$

＜For Water-borne coatings＞

$$VOC_{\_emission} = d \times \rho \times \frac{1}{\eta} \times \frac{R_{\_voc}}{R_{\_solid}} \times (1 - \eta \times \alpha \times R_{\_red}) \quad (7)$$

The product of the first to the fourth terms of the equation in formulas (6) and (7) is the same as with formulas (4) and (5), respectively, and expresses the volume of diluted coating. The fifth term of the equation ($1 - \eta \times \alpha \times R_{\_red}$) expresses the emission factor (the amount emitted as a ratio of the volume used).

$$EF = 1 - \eta \times \alpha \times R_{\_red} \quad (8)$$

The formulae used to estimate the VOC use volume, the amount of VOCs emitted to air, and the emission factor per unit area of the object coated are constructed as described above. As a result, the quantitative relationship between VOC volume and the reduction in VOC emissions and parameters such as the transfer efficiency, the rate of transfer to the drying oven, and the rate of removal of VOCs by a deodorizer can be clarified. We collected and studied representative values for the parameters used in the emission formula. In the following chapter, from these representative parameters for the coating process, we extract representative parameters for each industry sector, for each type of coating, and for each method of coating. In addition, we verify the validity of the VOC emission estimation formula by applying actual values taken from real coating cases.

3. Representative values of coating process parameters used in the emission estimation formula

In this chapter, we give representative values (extracted from documents and other sources) of the coating process parameters used in the emission estimation formula; the values are classified in detail in terms of industry sector, coating method, coating type, and the object being coated. If any parameter used in the estimation formula is unknown, the parameters listed in this chapter can be used to estimate VOC use volumes and emissions.

3.1 Coating film thickness (*d*)

Representative coating film thicknesses per industry are shown in Table 3.1. The coating film thicknesses in Table 3.1 were provided by the Ministry of Economy, Trade, and Industry (2006) as specific qualities required by each industry in accordance with differences in the objects being coated, the coating process itself, and the use conditions. Coating film thickness (*d*) is one parameter that provides information that can help estimate the amount of solid components attached to the coated product as a coating film.

Table 3.1 Representative coating film thicknesses per industry sector

Industry	Coating thickness (μm)
Building	80–150
Construction materials	20–50
Construction	80–200
Shipbuilding	150–500
Automobiles (new cars)	50–80
Automobile refinishing	20–40
Electronics equipment	20–40
Machinery	40–60
Metal products	20–40
Wood products	40–100
Home use	10–40
Traffic paints	700–1500
Other	20–30

Source: Ministry of Economy, Trade and Industry (2006)

3.2 Specific gravity of solid components (ρ)

Representative specific gravities of the resins used in coatings are shown in Table 3.2. These values are thought to represent the specific gravity of the coating film attached to the coated object—in other words, the weight ratio of solid components in the coating. By multiplying the specific gravity of the solid component (ρ) by the coating film thickness (d) in the previous section, the weight of the solid components attached to the coated product can be estimated.

Table 3.2 Specific gravities of resins used in coatings

Resin	Specific gravity
Urethane resin	1.2
Vinyl resin	1.23–1.45
Polyvinyl acetate resin	1.19
Unsaturated polyester resin	1.0–1.2
Vinyl ester resin	1.0–1.2
Ketone resin	1.18–1.20
Polyester resin	1.1–1.3
Epoxy resin	1.19
Polyethylene resin	0.91–0.97

Source: Sakurauchi (1987) and the Japan Paint Manufacturers Association (2004b)

3.3 Transfer efficiency (η)

The transfer efficiency is represented by the proportion of the coating that is attached to the object to be coated when a coating is sprayed by using various apparatus. Actual measurements of transfer efficiency per item of apparatus used and per coated object are shown in Table 3.3. The weight of the coating film (solid component) on the coated object can be expressed as the product of multiplication of the weight of the solid components in the diluted coating by the transfer efficiency (η). Thus, the amount of solid components in a diluted coating can be derived by multiplying the weight of the coating film (solid component) on the coated object by the reciprocal of the transfer efficiency ($1 / \eta$).

Table 3.3 Transfer efficiency per coating method per object to be coated (%)

coating method		Flat plate	Beverage can		Large-diameter tube	Aluminum building materials	Automobiles		Electronics equipment	Wooden building materials	Construction machinery and railroad vehicles
			Interior	Exterior			Top coat	Interior			
Air spray		40–50	50–60	20–30	—	20–30	20–30	40–50	30–40	40–50	50–60
Low-pressure air		50–60	60–70	30–40	—	30–40	—	50–60	40–50	50–60	50–60
Airless		60–70	80–90	60–70	70–80	40–50	—	—	—	60–70	60–70
Air-assisted airless		65–75	80–90	60–70	75–85	40–50	—	—	—	65–75	65–75
Electrostatic spraying	Air	60–70	—	60–70	—	60–70	40–50	70–80	60–70	60–70	65–75
	Airless	70–80	—	80–90	—	65–75	—	—	—	70–80	70–80
	Bell	80–90	—	—	—	75–85	60–70	—	70–80	80–85	80–90
	Disc	—	—	—	—	—	—	—	—	—	—

Source: Japan Chemical Industry Association et al. (2001)

3.4 Rate of transfer to the drying oven (α)

The rate of transfer to the drying oven is the percentage of VOCs in the diluted coating that is sprayed onto a coated object and becomes a coating film and thus is transferred into the drying oven with the coating film. Rates of transfer to the drying oven per industry sector are shown in Table 3.4. In cases where a drying oven is not used (e.g. for coatings applied outside), **α** = 0 and thus the emission factor in formula (8) becomes 1.

Table 3.4 Rates of transfer of VOC components in diluted coatings to a drying oven

Industry sector	Rate of transfer to drying oven
Automobile (new)	0.2
Other	0.1

Sources: Ministry of the Environment (2004) and Japan Chemical Industry Association et al. (2001)

3.5 Ratio of VOC components in coating (*R_voc*)

The ratio of VOC components in the coating is derived by adding together the proportions of each solvent component (from the list of solvent components for standard coating items per industry sector, as described by the Japan Paint Manufacturers Association, 2010). The ratio of VOC components in each type of coating is listed per industry sector in Table 3.5.

3.6 Ratio of solid components in coating (*R_solid*)

The ratios of solid components in each type of coating per industry sector are shown in Table 3.6. In solvent-borne coatings, it is assumed that components other than the VOC component in coated products are solid components. Thus the ratio of solid components in the coating is derived by subtracting the ratio of VOC components from 100%. In the case of water-borne coatings, because water is one of the three major components (along with solid components and VOCs), the sum of the water ratio and the ratio of VOC components is subtracted from 100% to obtain the ratio of solid components.

3.7 Thinner dilution rate (*R_thinner*)

The thinner dilution rate is the proportion of thinners added to the coating when the coating is taken as 100%. The thinner dilution rates for each coating type per industry sector, based on data from the Japan Paint Manufacturers Association (2010), are shown in Table 3.7.

Table 3.5 Ratios of VOC components in each type of coating per industry sector (%)

Source: Based on the Japan Paint Manufacturers Association (2010)

Coating type				Buildings	Construction materials	Construction	Shipbuilding	Automobiles (new)	Automobile refinishing	Electronics equipment	Machinery	Metal products	Wood products	Home use	Traffic paints	Other
Lacquers				49	54	50	24	66	55	54	62	62	60	43	68	77
Electrical insulating coatings				–	–	–	–	–	–	19	–	–	–	–	–	–
Synthetic resin coatings	Solvent-borne type	Alkyd resin systems	Varnishes and enamels	37	31	26	29	49	38	28	35	36	27	40	23	49
			Ready-mixed paint	24	32	19	28	46	32	21	27	29	–	30	20	51
			Anticorrosive paint	26	32	25	29	29	33	36	34	34	45	31	–	35
			Anticorrosive paint (high-solids)	23	27	20	23	19	19	29	24	24	–	23	–	–
		Amino-alkyd resin systems		13	37	31	21	32	38	27	31	33	44	–	–	42
		Acrylic resin systems	Air-drying type	35	45	41	34	56	49	59	36	44	52	34	19	68
			Baking type	–	44	35	–	49	36	34	33	38	51	–	–	61
			Baking type (high-solids)	–	29	–	–	36	–	30	29	27	–	–	–	26
		Epoxy resin systems	General type	45	48	30	24	48	47	38	40	60	33	36	–	42
			High-solids type	8	13	25	16	34	–	23	26	24	22	–	–	17
		Urethane resin systems		37	41	26	26	52	42	43	34	45	50	46	–	56
		Unsaturated polyester resin systems		38	28	33	11	53	11	42	16	31	29	–	–	27
		Ship-bottom paints	General type	34	36	32	26	39	–	34	39	32	39	35	–	64
			High-solids type	25	26	17	19	–	–	–	–	–	–	–	–	–
		Other solvent systems	Vinyl resin systems	46	56	61	55	52	–	77	70	66	57	50	30	60
			Chlorinated rubber systems	74	36	32	32	32	–	10	5	34	–	–	–	–
			Silicone and fluorocarbon resin systems	33	49	31	40	59	41	35	35	44	44	30	–	55
			Other	33	39	26	33	47	50	32	44	42	39	40	26	49
	Water-borne type	Emulsion paints		3	3	7	9	2	3	5	5	13	0	3	2	12
		Thick film emulsion coatings		2	4	0	1	1	0	1	1	8	–	3	–	3
		Water-based resin coatings		3	7	2	1	3	7	6	7	11	0	4	0	8
	Non-solvent type	Powder coatings		–	0	0	0	0	–	0	0	0	–	–	0	0
		Traffic paints		–	–	–	–	–	–	–	–	–	–	0	0	0
		Solvent-free epoxy resin coatings		0	0	0	0	–	–	–	–	–	0	–	1	0
		Solvent-free urethane resin coatings		0	0	0	–	–	–	–	0	–	–	–	–	–
Other coatings				5	10	14	37	15	21	36	18	14	29	18	20	23

Table 3.6 Ratios of solid components in each type of coating per industry sector (%) Source: Based on Japan Paint Manufacturers Association (2004a and 2010)

Coating type				Buildings	Construction materials	Construction	Shipbuilding	Automobiles (new)	Automobile refinishing	Electronics equipment	Machinery	Metal products	Wood products	Home use	Traffic paints	Other
Lacquers				51	46	50	76	34	45	46	38	38	40	57	32	23
Electrical insulating coatings				–	–	–	–	–	–	81	–	–	–	–	–	–
Synthetic resin coatings	Solvent-borne type	Alkyd resin systems	Varnishes and enamels	63	69	74	71	51	62	72	65	64	73	60	77	51
			Ready-mixed paints	76	68	81	72	54	68	79	73	71	–	70	80	49
			Anticorrosive paints	74	68	75	71	71	67	64	66	66	55	69	–	65
			Anticorrosive paints (high-solids)	77	73	80	77	81	81	71	76	76	–	77	–	–
		Amino-alkyd resin systems		87	63	69	79	68	62	73	69	67	56	–	–	58
		Acrylic resin systems	Air-drying type	65	55	59	66	44	51	41	64	56	48	66	81	32
			Baking type	–	56	65	–	51	64	66	67	62	49	–	–	39
			Baking type (high-solids)	–	71	–	–	64	–	70	71	73	–	–	–	74
		Epoxy resin systems	General type	55	52	70	76	52	53	62	60	40	67	64	–	58
			High-solids type	92	87	75	84	66	–	77	74	76	78	–	–	83
		Urethane resin systems		63	59	74	74	48	58	57	66	55	50	54	–	44
		Unsaturated polyester resin systems		62	72	67	89	47	89	58	84	69	71	–	–	73
		Ship bottom paint	General type	66	64	68	74	61	–	66	61	68	61	65	–	36
			High-solids type	75	74	83	81	–	–	–	–	–	–	–	–	–
		Other solvent systems	Vinyl resin systems	54	44	39	45	48	–	23	30	34	43	50	70	40
			Chlorinated rubber systems	26	64	68	68	68	–	90	95	66	–	–	–	–
			Silicone and fluorocarbon resin systems	67	51	69	60	41	59	65	65	56	56	70	–	45
			Other	67	61	74	67	53	50	68	56	58	61	60	74	51
	Water-borne type[1]	Emulsion paints		47	47	43	41	48	47	45	45	37	50	47	48	38
		Thick-film emulsion coatings		48	46	50	49	49	50	49	49	42	–	47	–	47
		Water-based resin coatings		47	43	48	49	47	43	44	43	39	50	46	50	42
	Non-solvent type	Powder coatings		–	100	100	100	100	–	100	100	100	–	–	100	100
		Traffic paints		–	–	–	–	–	–	–	–	–	–	100	100	100
		Solvent-free epoxy resin coatings		100	100	100	100	–	–	–	–	–	100	–	99	100
		Solvent-free urethane resin coatings		100	100	100	–	–	–	–	100	–	–	–	–	–
Other coatings				95	90	86	63	85	79	64	82	86	71	82	80	77

[1] The water ratio (50%) used to obtain the ratio of solid components in water-borne coatings is calculated on the basis of the following assumptions: the water ratio in coatings is 53% (including dilution water), based on Japan Paint Manufacturers Association (2004a); and the water dilution rate is 5%, based on Nippon Paint Co., Ltd. (2011) and Kansai Paint Co., Ltd. (2011).

Table 3.7 Thinner dilution rates per coating type per industry sector (%)

Source: Japan Paint Manufacturers Association (2010)

Coating type				Buildings	Construction materials	Construction	Shipbuilding	Automobiles (new)	Automobile refinishing	Electronics equipment	Machinery	Metal product	Wood products	Home use	Traffic paints	Other
Lacquers				35	20	16	3	60	42	42	60	60	64	4	50	28
Electrical insulating coatings				–	–	–	–	–	–	6	–	–	–	–	–	–
Synthetic resin coatings	Solvent-borne type	Alkyd resin systems	Varnishes and enamels	16	9	5	11	9	29	12	25	11	18	8	2	21
			Ready-mixed paints	10	8	8	6	16	3	9	18	12	–	6	1	10
			Anticorrosive paints	12	7	11	5	3	4	9	22	22	0	6	–	20
			Anticorrosive paints (high-solids)	10	9	7	4	2	2	8	15	12	–	8	–	–
		Amino-alkyd resin systems		3	23	7	10	17	20	25	20	22	20	–	–	15
		Acrylic resin systems	Air-drying type	38	42	16	6	43	55	43	25	29	24	5	2	21
			Baking type	–	27	10	–	49	30	31	18	28	15	–	–	16
			Baking type (high-solids)	–	11	–	–	19	–	15	20	17	–	–	–	12
		Epoxy resin systems	General type	11	10	10	8	21	14	25	20	14	13	8	0	14
			High-solids type	1	5	6	5	10	–	13	12	7	10	–	–	0
		Urethane resin systems		13	12	6	8	53	52	27	23	23	38	9	–	19
		Unsaturated polyester resin systems		0	2	1	3	6	0	33	5	12	12	–	–	6
		Ship bottom paint	General type	4	10	10	4	0	–	10	14	10	0	0	–	9
			High-solids type	4	3	5	3	–	–	–	–	–	–	–	–	–
		Other solvent systems	Vinyl resin systems	25	10	16	12	18	–	35	34	8	50	18	5	32
			Chlorinated rubber systems	1	7	10	5	15	–	10	10	10	–	–	–	–
			Silicone and fluorocarbon resin systems	11	11	9	5	15	9	15	12	11	18	1	–	30
			Other	11	52	10	6	31	47	27	30	8	20	9	3	22
	Water-borne type	Emulsion paints		0	0	0	0	0	0	0	0	0	0	0	0	9
		Thick-film emulsion coatings		0	0	0	0	0	0	0	0	0	–	0	–	0
		Water-based resin coatings		0	0	0	0	0	0	0	0	0	0	0	0	2
	Non-solvent type	Powder coatings		–	0	0	0	0	–	0	0	0	–	–	0	0
		Traffic paints		–	–	–	–	–	–	–	–	–	–	0	0	0
		Solvent-free epoxy resin coatings		0	0	0	0	–	–	–	–	–	0	–	0	0
		Solvent-free urethane resin coatings		0	0	0	–	–	–	–	0	–	–	–	–	–
Other coatings				2	7	10	7	3	1	10	20	8	8	3	1	11

3.8 Rates of removal of VOCs by deodorizer (*R_red*)

Rates of VOC removal by deodorizer are shown in Table 3.8.

Table 3.8 Rates of removal of VOCs by deodorizer (exhaust-gas treatment equipment)

Type of treatment equipment	VOC removal rate
Combustion equipment	0.995
Activated carbon absorption equipment	0.8

Source: Japan Chemical Industry Association et al. (2001)

4. Evaluation of the validity of the estimation formula

The validity of the estimation formula is evaluated by comparing the actual values taken from real coating cases and the estimated values derived by using the method introduced in this ESD.

4.1 Actual values in real coating cases

The actual values in real coating cases are shown in Table 4.1. The actual values of VOC emissions are calculated as emissions per unit of coated area on the basis of the use of coating per month, the area coated per month, and the rate of evaporation of VOCs from the applied coatings.

Table 4.1 Actual values in real coating cases

No.	Industry sector (coated object)	Type of coating	Method of coating	Area coated per month	Use of coating per month	Rate of VOC evaporation from applied coatings	Volume of coating used[1]	Actual amount of VOC emissions[1]
				m^2	t	%	g/m^2	g/m^2
1	Electronics equipment (Mobile phones)	Solvent-borne Amino acrylic	Low-pressure gun	4000	7	32	1750	560
2	Wood products (Furniture)	Solvent-borne Urethane	Electrostatic bell	13,000	5	51	385	196
3	Wood products (Cabinets)	Solvent-borne Urethane	Brush + spray	6000	3.42	77	570	439
4	Metal products (Steel furniture)	Water-borne Amino-alkyd	Static electricity	50,000	3.6	9	72	6.5
5	Machinery (Parts)	Water-borne Amino-alkyd	Electrostatic air	8000	3.5	8	438	35
6	Machinery (Parts)	Solvent-borne Amino-alkyd	Electrostatic air	24,000	6	56	250	140
7	Electronics equipment (Electronics products)	Solvent-borne Acrylic silicone	Electrostatic air	7200	1.2	37	167	62
8	Automobile (New car bodies)	Water-borne + Solvent-borne Amino acrylic	Electrostatic bell	200,000	43.3	20	217	43
9	Construction	Water-borne	Electro-	450,000	17.1	18	38	6.8

	materials (Aluminum panels)	Acrylic melamine	deposition coating					
10	Construction materials (Building panels)	Water-borne Emulsion	Roller + Airless	270,000	30	4	111	4.4
11	Construction materials (Ceramic board)	Water-borne Emulsion	Roller + Airless	65,000	8	0.5	123	0.62
12	Construction materials (Plasterboard)	Water-borne Emulsion	Roller	154,000	22	24	143	34
13	Construction materials (Inorganic exterior materials)	Water-borne Emulsion	Airless	96,000	28.6	0	298	0
14	Construction materials (Tiles)	Water-borne Emulsion	Airless	14,000	7.2	13	514	67
15	Construction materials (Inorganic building materials)	Water-borne Emulsion	Shower coat	336,000	26	0	77	0

Source: As described by the Japan Paint Manufacturers Association (2004a) ([1] Calculations based on stated values)

4.2 Coating-process parameters used for estimations in the method introduced in this ESD

The coating-process parameters shown in Table 4.2 are used to estimate VOC emissions by using the method introduced in this ESD. These coating process parameters were chosen by applying the representative values (Tables 3.1 to 3.8) for each of the corresponding items in the actual data to the categories of industry sector, coating method, coating type, and object to be coated (Table 4.1). In cases where there was a range of representative values, the mean value was used. Also, for coatings (resins) not listed in Table 3.2, the specific gravity of the solid components was assumed to be 1. The value for an electrostatic bell coating was used as the transfer efficiency for those coatings other than spray coatings. The VOC removal rate (*R_red*) was set to 0, assuming that there was no deodorization treatment equipment installed.

Table 4.2 Coating-process parameters entered into the estimation formula

No.	Coating film thickness *(d)*	Specific gravity of solid component *(ρ)*	Transfer efficiency *(η)*	Rate of transfer to drying oven *(α)*	Weight ratio of VOC components in coating *(R_voc)*	Weight ratio of solid components in coating *(R_solid)*	Thinner dilution rate *(R_thinner)*
	µm	g/mL	%		%		
1	30	1	45	0.1	59	41	43
2	70	1.2	83	0.1	50	50	38
3	70	1.2	55	0.1	50	50	38
4	30	1	65	0.1	7	43	0
5	50	1	65	0.1	7	43	0
6	50	1	70	0.1	31	69	20
7	30	1	65	0.1	34	66	31
8	65	1	65	0.2	49	51	49
9	35	1	80	0.1	7	43	0
10	35	1	75	0.1	3	47	0
11	35	1	75	0.1	3	47	0
12	35	1	85	0.1	3	47	0
13	35	1	75	0.1	3	47	0
14	35	1	75	0.1	3	47	0
15	35	1	85	0.1	3	47	0

Sources: Sakurauchi (1987), Japan Paint Manufacturers Association (2004b), Ministry of the Environment (2004), Japan Chemical Industry Association et al. (2001)

4.3 Comparison between actual and estimated values

We compared the actual values of VOC emissions (as shown in the coatings cases in Table 4.1) and the estimated values, as derived by entering the coating process parameters (Table 4.2) into the estimation formula (Figure 4.1). The estimated values were mostly within the range of 1/10 to 10 times the actual values, thus confirming the validity of the estimation formula. This suggests that, even when detailed data on a coating process parameter are not available, by using information on industry type, coating type, and coating method the amount of VOC emissions can be estimated with sufficient accuracy by using the method introduced in this ESD.

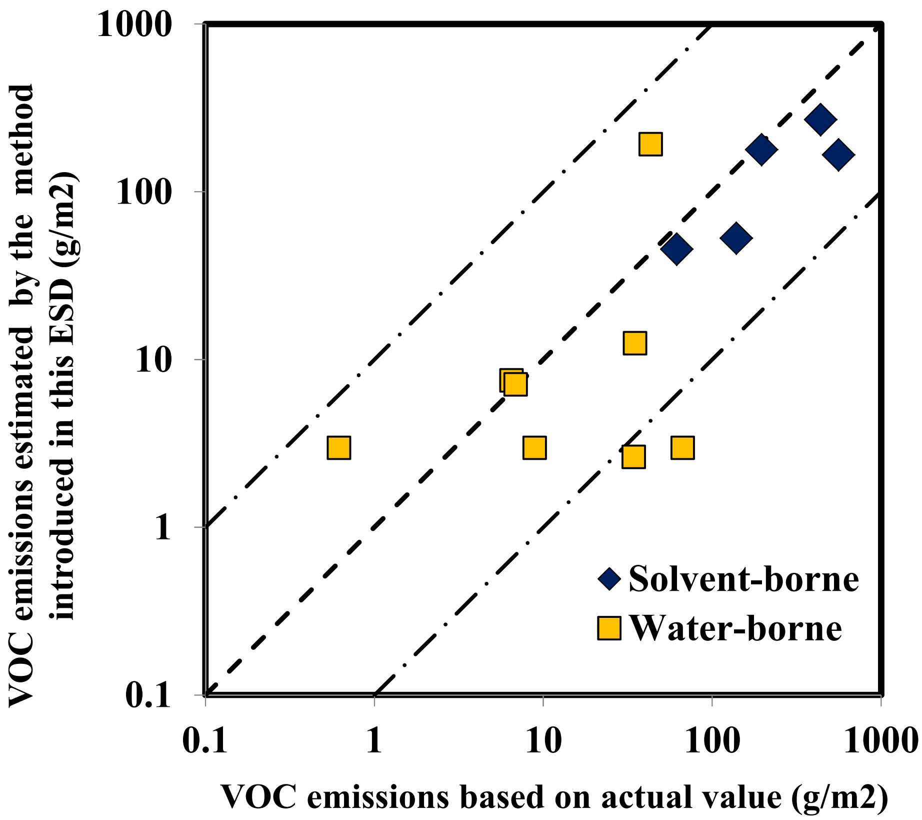

Figure 4.1 Comparison of actual and estimated values of VOC emissions

Appendix

A. Model calculations

By using the estimation method explained in Chapter 2, VOC emissions are calculated for a case with a solvent-borne coating and another case with a water-borne coating by entering the assumed specific parameters into the emission estimation formula.

A.1 Example of calculation of VOC emissions from solvent-borne coatings

"Machinery" is assumed to be the industry sector for the estimation of emissions from the solvent-borne coating. VOC emissions are estimated by using the emission estimation formula (6) for a solvent-borne coating, as described in Section 2.3.

$$VOC_{\_emission} = d \times \rho \times \frac{1}{\eta} \times \frac{R_{\_voc} + R_{\_thinner}}{R_{\_solid}} \times (1 - \eta \times \alpha \times R_{\_red}) \qquad (6)$$

As input parameters for formula (6), the following numerical values are entered:

d (coating film thickness): 50 μm. This is the representative coating film thickness as shown in Table 3.1 (the average coating film thickness for the industry sector "machinery").

ρ (specific gravity of solid component): 1.2 g/cm^3. This is the specific gravity of resin (urethane system) in a coating (based on Table 3.2).

η (transfer efficiency): 65%. Airless coating of a flat plate is assumed (see Table 3.3).

α (transfer rate to drying oven): 0.1. The value for the "Other" industry sector, which is the value for all industries other than automobile (new), is shown in Table 3.4.

R_voc (weight ratio of VOC components in coating): 34%. This is the ratio of VOC components in "urethane resin system" coatings in the industry sector "machinery" (see Table 3.5).

R_solid (weight ratio of solid components in coating): 66%. This is the ratio of solid components in "urethane resin system" coatings in the industry sector "machinery" (see Table 3.6).

R_thinner (thinner dilution rate; weight ratio of thinner to coating): 23%. This is derived from the ratio of solid components in "urethane resin system" coatings in the industry sector "machinery" (see Table 3.7).

R_red (rate of VOC removal by deodorizer): 0.995. This value is for combustion equipment (see Table 3.8).

When the above parameters are substituted into formula (6),

$$VOC_{\_emission} = 50 \times 1.2 \times \frac{1}{0.65} \times \frac{0.34 + 0.23}{0.66} \times (1 - 0.65 \times 0.1 \times 0.995)$$

the calculation yields a $VOC_{\_emission}$ (VOC emissions) value of 74.6 g/m^2. When the emission factor (*EF*) is calculated, as per formula (8) in Section 2.3, the result is 0.935.

A.2 Example of calculation of VOC emissions from water-borne coatings

"Automobile" is assumed to be the industry sector for the estimation of emissions from a water-borne coating. VOC emissions are estimated by using the emission estimation formula (7) for water-borne coatings, as described in Section 2.3:

$$VOC_{\_emission} = d \times \rho \times \frac{1}{\eta} \times \frac{R_{\_voc}}{R_{\_solid}} \times (1 - \eta \times \alpha \times R_{\_red}) \qquad (7)$$

As input parameters, the following numerical values are entered:

d (coating film thickness): 65 µm. The representative coating film thickness is shown in Table 3.1 (the average coating film thickness for the industry sector "automobile (new)" is used).

ρ (specific gravity of solid component): 1.1 g/cm^3. Specific gravity in unsaturated polyester resin systems is assumed (see Table 3.2).

η (transfer efficiency): 45%. Top coat coating by using electrostatic air in the automotive (new) sector is assumed (see Table 3.3).

α (rate of transfer to drying oven): 0.2. The value for the automotive (new) sector is shown in Table 3.4.

R_voc (weight ratio of VOC components in coating): 3%. The ratio of VOC components in a "water-based resin coating" in the industry sector "automobile (new)" is assumed (see Table 3.5).

R_solid (weight ratio of solid components in coating): 47%. The ratio of solid components in a "water-based resin coating" in the industry sector "automobile (new)" is assumed (see Table 3.6).

R_red (VOC removal rate of a deodorizer): 0. It is assumed that a deodorizer will not be used.

When the above parameters are substituted into formula (7),

$$VOC_{\_emission} = 65 \times 1.1 \times \frac{1}{0.45} \times \frac{0.03}{0.47} \times (1 - 0.45 \times 0.2 \times 0)$$

the calculation yields a $VOC_{\_emission}$ (VOC emissions) value of 10.1 g/m^2. The emission factor (*EF*) is 1, because it is assumed that a deodorizer will not be used; thus, R_red (rate of VOC removal by deodorizer) is 0.

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