National Pollutant Inventory

Emission Estimation Techniques Manual

for

Furniture and Fixtures Manufacturing

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EMISSION ESTIMATION TECHNIQUES
FOR
FURNITURE AND FIXTURES MANUFACTURING

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FURNITURE AND FIXTURES MANUFACTURING

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1.0 Introduction

The purpose of all Emission Estimation Technique (EET) Manuals in this series is to assist Australian manufacturing, industrial and service facilities to report emissions of listed substances to the National Pollutant Inventory (NPI). This Manual describes the procedures and recommended approaches for estimating emissions from facilities engaged in furniture and fixture manufacturing.

Activities covered by this Manual include wooden structural component manufacturing, wooden furniture and upholstered seat manufacturing, and metal furniture and fittings manufacture.

EET MANUAL: Furniture and Fixtures Manufacturing

HANDBOOK: Furniture Manufacturing

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This Manual was drafted by the NPI Unit of the Queensland Department of Environment and Heritage on behalf of the Commonwealth Government. It has been developed through a process of national consultation involving State and Territory environmental authorities and key industry stakeholders.

2.0   Process Description

This Manual focuses on the household and office furniture manufacturing industry because the majority of the wood and metal furniture manufacturing facilities in Australia are engaged in manufacturing household furniture goods.   The industry covers the production of many different types of products including wood household furniture, metal household furniture, machine cabinets, shelving, and wardrobes. Because the items produced vary greatly in design depending upon the type of material used, style, price, and final use, the different types of machinery used in the various phases of production can reach into the hundreds or even thousands. The diversity of products provides a challenge for most manufacturers and means that the emission estimation techniques covered in this Manual are equally varied and complex.

Production lines for assembling furniture are costly, and because of this most manufacturers do not supply an exceptionally large range of items. To combat this problem, many firms specialise their production processes, allowing facilities to fill a specific niche in the market while still retaining flexibility in their manufacturing area. Manufacturers may specialise depending on the product manufactured, the product group, or the production process. Specialisation has also allowed manufacturers to focus on quality by more carefully monitoring the entire production process, from raw material to finished product.

Because of the number of products covered by the furniture and fixtures industry, much of this Manual concentrates on the following furniture product categories defined by the furniture manufacturing industry:

- Household furniture including beds, tables, chairs, and bookcases;
- Television cabinets and home-entertainment units, kitchen furniture, and sewing-machine cabinets;
- Office furniture including cabinets, chairs, desks, and filing cabinets;
- Public building and related furniture including stadium seats and bleachers; and
- Office and store fixtures, shop fittings, partitions, counters, shelving, and lockers.

All descriptions on production processes, emissions generated, and techniques for estimating emissions from the processes will be limited to these manufacturing activities.

2.1 Wood Furniture Process Description

The following description of production processes focuses on the manufacturing of wood furniture. The primary input for wood furniture manufacturing is raw timber and the production processes include steps such as drying, sawing, planing, sanding, gluing, and painting and finishing. Each of these activities can generate emissions of NPI-listed substances and is described below.

2.1.1 Drying

Some furniture manufacturing facilities may purchase dried timber, but others perform drying on-site. Drying of raw timber is accomplished by using a drying kiln or oven, fired by a boiler. Those that undertake on-site timber drying, by and large burn wood waste - obtained from later stages of the production process - in boilers to heat the drying-kilns and to alleviate possible solid-waste disposal problems. The following boiler firing configurations are used for burning wood waste: Dutch oven; fuel cell oven; spreader stoker; suspension-fired; and fluidised bed combustion. The primary outputs of burning wood waste in boilers are point-source emissions to the air. A more detailed discussion of all material inputs and pollutant emissions will be covered in the following section.

The *Combustion in Boilers* EET Manual provides a more detailed discussion of boiler combustion processes and provides detailed advice in estimating emissions from a range of fuels in various boilers under different firing configurations. The *Combustion in Boilers* EET Manual, and all other Manuals in this series, is available from all State and Territory environment agencies at the addresses shown in the front of the *NPI Guide*, and at the NPI Homepage.

2.1.2 Machining

Once the timber is dried, it is sawed into a shape of the approximate dimensions of the final furniture part, such as a table leg or a chair rung. Sawing across the grain is called crosscutting, and sawing parallel with the grain is referred to as ripping. Types of power saws used in furniture manufacturing include circular saws, band saws, scroll saws, radial saws, and portable handsaws.

After sawing, the surfaces of the wood that will be flat in the final product are planed. Planing involves shaving one surface of wood by using a wide edged blade, or blades, called a planer. The type of power planer usually used in this manufacturing process is the jointer or jointer planer, which consists of blades, fastened to a rotating cutterhead. The primary outputs from the sawing and planing processes are wood chips.

The design of some furniture pieces requires that certain wooden parts be bent. This production step follows the planing process and usually involves the application of pressure in conjunction with a softening agent and increased atmospheric pressure. Drying after bending is accomplished in much the same way as the drying of raw timber, in drying kilns that use boilers to generate heat.

2.1.3 Assembly

Wood furniture can either be finished (coated) and then assembled, or assembled and then finished. Residential and office/institutional furniture is generally made up of irregularly shaped, curved components, and for ease of production is assembled and then finished. More regular shaped products such as cabinets, however, are frequently finished before being assembled.

After the wood parts have been planed and, if necessary, bent, they are assembled to form one furniture part, such as a tabletop. The assembly process usually involves the use of adhesives (either synthetic or natural) in conjunction with other joining methods, such as nailing. The wood furniture manufacturing industry uses adhesive formulation containing solvents (typically used for upholstered wood furniture) and hot melts or polyvinyl acetate (typically used for non-upholstered wood furniture). The amount of adhesives used depends on the type of product.

The next step in the production process is the application of veneer. Veneer is a thin piece of wood of uniform thickness, which is usually rotary-cut from a bolt of wood using a lathe. Not all furniture manufacturing involves the application of veneer. The production of veneer is covered separately in the *Timber and Wood Product Manufacturing* EET Manual. The veneer application is applied to the furniture part using adhesives, some of which require the use of heat and/or pressure. While not a significant source of emissions of NPI-listed substances, gluing operations and the use of adhesives for assembly and veneer are a source of atmospheric solvent emissions.

After veneer application or furniture assembly, the furniture part is sanded to ensure that its surface is as smooth as possible for the finishing stages of the production process. Sanding is usually accomplished by a disk, belt, or roller-sanding machine using either open or closed-coated sandpaper. For open-coated sandpaper, approximately 50 to 70 percent of the paper surface is coated with abrasive. For close-coated sandpaper, the paper surface is completely covered with abrasive. Close-coated sandpaper is generally used in operations requiring higher removal rates. The sanding process can also be employed at other stages of the production process, such as prior to the application of veneer or between the application of several coats of varnish during the finishing process. The primary emissions from sanding are wood particulates (PM_{10}).

2.1.4 Pre-Finishing

After initial sanding, an even smoother surface is attained by spraying, sponging, or dipping the furniture part with water, which causes the fibres of the wood to swell and rise. After the surface is dried, a solution of glue or resin is applied and allowed to dry, causing the raised fibres to become more brittle. The raised fibres are then sanded down to form a particularly smooth surface. The primary emission from second sanding is PM_{10}, comprising wood and glue or resin particulates.

Because certain types of wood contain rosin (a naturally occurring resin) which can interfere with the effectiveness of certain finishes, a process known as derosination may be employed. Derosination is accomplished by applying a mixture of acetone and ammonia to the surface of the wood. Spent acetone and ammonia, both NPI-listed substances, are the primary emissions from derosination.

Once the unwanted rosin is removed from the wood, a process known as bleaching is used to lighten the colour of the wood when the natural colour is darker than that of the stain or finish to be applied. The process entails spraying, sponging, or dipping the wood into a bleaching agent, such as hydrogen peroxide. Spent bleaching agents, some of which may contain NPI-listed substances, are the primary emissions of this step of the production process.

2.1.5 Coating Application

There are various coating applications used by the wood furniture manufacturing industry. The two principal methods are flatline finishing and spray application. Flatline finishing is used only to coat truly flat furniture parts and cannot be used for curved pieces, pre-assembled pieces, or pieces with many recesses. Although spray application is the most commonly used method to finish these furniture parts, brushing and dipping can also be used.

The two principal ways of performing flatline finishing are roll coating and curtain coating. Roll coating involves the transfer of coating material by a roller or series of rollers, while curtain coating involves passing the furniture part through a cascade, or curtain, of coating material.

The methods used to apply spray coatings include air, airless, air-assisted airless, high volume low-pressure (HVLP), electrostatic methods, and the UNICARB® spray system. The conventional air spray technique uses compressed air to atomise the coating materials as they are being sprayed, by forcing them through a small opening at high pressure. The liquid coating is not mixed with air before exiting the nozzle. Air-assisted airless spray uses an airless spray unit with a compressed air jet to finalise the break-up of the coating material. HVLP spraying involves the use of a high volume of air delivered at low pressure to atomise the coating material into a pattern of low-speed particles. The use of low pressure can result in decreased overspray, which translates into less coating usage and fewer emissions of NPI-listed volatile organic compounds (VOCs).

Electrostatic spraying has long been used in the metal working and motor vehicle industries to coat metal products. In the wood furniture industry, electrostatic spraying has somewhat limited use, mostly by cabinet and chair manufacturers. This finishing process is performed by spraying negatively-charged coating particles onto positively-charged wood products. If the wood piece has a sufficient moisture content, it can be electrostatically sprayed without pre-treatment. However, some wood must be pre-treated to allow the piece to hold a positive charge. The material used for pre-treatment often contains VOCs.

The UNICARB® system is a relatively new system for spray coating developed by Union Carbide. A coating normally contains both coalescing (slow-evaporating) and diluent (fast-evaporating) solvents. The UNICARB® technology replaces the diluent solvents with liquid carbon dioxide. The carbon dioxide/coalescing solvent coating mixture is used to coat the wood with an airless spray gun. When the coating leaves the spray nozzle, the carbon dioxide in the mixture immediately flashes, and the coating material, which still contains coalescing solvents, continues en-route to the piece and cures in the conventional way.

2.1.6 Finishing

The finishing of wood furniture can be subdivided into two different categories, interior finishing (furniture for indoor use) and exterior finishing (furniture for outdoor use), although the actual production processes involved are fairly similar. The main difference between interior and exterior finishing is the type of coating material applied, not the application processes. The following description outlines the production processes involved in interior finishing; exterior finishing will be mentioned only when the process differs from that on interior finishing.

Wood finishing processes include coating, drying, and sanding the furniture in a series of steps that are repeated until the desired final appearance is achieved. While in small facilities the assembled furniture is sometimes moved between finishing stations manually, in most facilities the furniture is moved along the finishing line mechanically by tow-lines, overhead chain conveyors, and other conveyors including belt, roller, and slat conveyors. The pallets can rotate and can be automatically disengaged from and re-engaged to the tow-line to allow for pauses, as needed. Some facilities move the furniture on pallets that are hung from overhead chain conveyors. Many facilities use a combination of these methods to transport the furniture along the finishing line. With the exception of electric engines, emission estimation techniques relevant to the use of these tow and conveyor devices are contained the *Combustion Engines* EET Manual.

Many of the finishing application methods use relatively high concentrations of VOCs which volatilise when the coating is applied. For example, solvents are used in the stains, paints, and finishes as well as in the inks used to print simulated wood grain onto plywood and particleboard. In addition, solvents are used in clean-up operations (that is, to remove overspray from spray booths and to rinse solvent-based finishes from spray lines and equipment between colour changes). The primary outputs from the following finishing applications are point-source as well as fugitive air emissions.

Staining involves the application of a clear colorant, which adds initial colour, evens out the colour, and accents without hiding the natural wood grain. Stains usually consist of transparent or semi-transparent colour solids (typically less than five percent by volume) suspended in a volatile liquid solution with a certain amount of a non-volatile binder, which facilitates spreading, penetration, and fixation of colour. Commonly used stains, all of which are used in conjunction with organic solvents, include; non-grain-raising, dye-type, no-wipe, and toners.

Non-grain raising stains are dye-type stains that are intended to give clarity and depth to the wood finish. Dye-type stains consist of dyes that are completely dissolved in methanol. No-wipe stains are pigmented stains, containing a small amount of oil, pigment, and solvent, which are sprayed on and not wiped off. No-wipe stains are used to accent the wood grain, provide colour uniformity and colour retention. Toners are stains that contain nitrocellulose or vinyl binders, dissolved in solvent. Toners are not wiped, and are often pigmented.

After staining, a washcoat, consisting of two to 13 percent solids by volume, is applied to the furniture piece. Washcoating is used to aid in adhesion, assist in filling or colour uniformity, and partially seal the wood from subsequent staining operations. Washcoat also prepares the wood surface for another sanding after stain application. Some facilities

buy sealer in bulk, and dilute their sealer to make washcoat. There are three main types of washcoat materials: standard nitrocellulose; vinyl or modified vinyl; and vinyl-modified *conversion* types. Advantages of nitrocellulose washcoats include quick drying, easy sanding, and clarity. Vinyl and vinyl-modified washcoats consist of nitrocellulose and vinyl and provide better toughness and adhesion than pure nitrocellulose washcoats; however, some clarity is sacrificed. The *conversion* or precatalysed-type washcoats also provide good adhesion and toughness, and are good for open pore woods. Because they react in place, they are impervious to solvents contained in subsequently applied sealers and topcoats.

Fillers are applied to the wood surface to produce a smooth, uniform surface for later stages in the finishing process. Fillers, which consist of colourless or covering pigments, can be combined with stains or other pigments and are usually dispersed in a vehicle of drying oils, synthetic resins, and thinners based on organic solvents. Fillers are usually supplied as heavily pigmented, high-solids, low-VOC materials, which are reduced on the job. As supplied, solids contents of fillers are in the 75 percent solids by volume range. Once reduced, the solids contents usually range from 10 to 45 percent by volume. Fillers are usually spray-applied, then wiped into the wood.

Sealing, which is completed after staining and either before or after filling, consists in applying one or many coats of sealer. Sealers are usually a nitrocellulose-based lacquer, although vinyl or vinyl-modified sealers and catalysed sealers are also available and provide advantages similar to those of the washcoat counterparts. The primary purposes of sealers are to provide adhesion, make sanding more effective, and to seal the wood and establish a foundation for further coating applications. Solids contents of sealers typically range from ten to 30 percent by volume.

For outdoor furniture, instead of, or in addition to, the filling and sealing processes, the wood surface is treated through a process known as priming. Priming treatments often used for outdoor furniture include the application of fungicides and water-repellents that may contain NPI-listed substances.

One alternative to staining is painting. The process for applying paints is similar to that of applying stains or other finishes, although the chemical composition of paints differs from the other finishes. Paint is a viscous fluid, usually consisting of a binder or vehicle, a pigment, a solvent or a thinner, and a drier. Pigments are insoluble in the coating material and are deposited onto the wood surface as the vehicle dries. The chemical composition of a pigment varies according to its colour as illustrated in Table 1.

Table 1 - Chemical Components of Pigments Found in Paint

Pigment Colour	Chemical Components
White	Titanium dioxide, white lead, zinc oxide
Red	Iron oxides, calcium sulfate, cadmium selenide
Orange	Lead chromate-molybdate
Brown	Iron oxides
Yellow	Iron oxides, lead chromate, calcium sulfide
Green	Chromium oxide, copper, phosphotungstic and molybdic acids
Blue	Ferric ferrocyanide, copper
Purple	Manganese phosphate
Black	Black iron oxide

Source: McGraw-Hill Encyclopaedia of Science and Technology, 1987.

After the furniture part has been stained or painted, a topcoat, such as a varnish or shellac, is applied in one of the final stages of the finishing process. Topcoats provide a clear coat whose function is to protect the colour coats, enhance the beauty of the furniture, and provide a durable final finish. Typical solids contents range from 13 to 30 percent solids by volume. There are four categories of topcoats: standard nitrocellulose topcoats; acrylic topcoats; catalysed topcoats; and conversion varnishes.

Rubbing, polishing, and cleaning are the final steps of the production process. Rubbing consists in the application of an abrasive in conjunction with a lubricant to level or dull the lustre. Polishing consists in the application of soft abrasives or possibly only waxy ingredients to increase the gloss. The furniture parts are then ready for shipment and sale after a final assembly stage, if appropriate (ie. attaching table legs to a tabletop).

2.2   Metal Furniture Process Description

Descriptions of the foundry processes involved in metal furniture and fixture manufacturing are contained in the *Ferrous Foundries* and *Non-Ferrous Foundries* EET Manuals and are not repeated here. These Manuals also contain emission estimation techniques for calculating emissions of NPI-listed substances from foundry and machining operations. This Manual describes processes, nominates likely emissions of NPI-listed substances, and offers techniques for estimating emissions of these listed substances from metal furniture and fixture surface coating activities.

The metal furniture surface coating process is a multi-step operation consisting of surface cleaning, coatings application, and curing. Items such as desks, chairs, tables, cabinets, bookcases, and lockers are normally manufactured from raw materials to finished product in the same facility. The industry uses primarily solvent-borne coatings, applied by spray, dip, or flow coating processes.

Spray coating is the most common application technique used. The components of spray coating lines vary from facility to facility, but generally include the following:

- 3- to 5-Stage Washer;
- Dryoff Oven;
- Spray Booth;
- Flashoff Area; and
- Bake Oven.

Items to be coated are first cleaned in the washer to remove any grease, oil, or dirt from the surface. The washer generally includes an alkaline cleaning solution, a phosphate treatment to improve surface adhesion characteristics, and a hot water rinse. The items are then dried in an oven and conveyed to the spray booth, where the surface coating is applied. After this application, the items are conveyed through the flashoff area to the bake oven, where the surface coating is cured. A diagram of these consecutive steps is presented at Figure 1 (see page 29). Although most metal furniture products receive only one coat of paint, some facilities apply a prime coat before the topcoat to improve the corrosion resistance of the product. In these cases, a separate spray booth and bake oven for application of the prime coat are added to the line, following the dryoff oven.

The coatings used in the industry are primarily solvent-borne resins, including acrylics, amines, vinyls, and cellulosics. Some metallic coatings are also used on office furniture. The solvents used are mixtures of aliphatics, xylenes, toluene, and other aromatics. Typical coatings that have been used in the industry contain 65 volume percent solvent and 35 volume percent solids. Other types of coatings now being used in the industry are water-borne, powder, and solvent-borne high solids coatings.

3.0   Emissions Sources and Control Technologies

The following description of NPI-listed substance inputs and pollutant emissions, and control technologies is organised along the same lines as the production process description. While there are emissions of NPI-listed substances to land and water, the vast majority of listed substance emissions from both wood and metal furniture and fixtures manufacturing are atmospheric emissions resulting from the solvent-intensive finishing operations.

3.1   Wood Furniture and Fixtures

The following description of production processes focuses on the emissions of NPI-listed substances from wood furniture and fixture manufacturing. The primary emissions occur from drying, machining, assembly, pre-finishing, coating application, finishing, and clean-up operations. The emissions of NPI-listed substances from each of these activities are described below.

3.1.1   Drying

This section on emissions from timber drying focuses on the use of wood-waste in boilers. To gain an understanding of likely emissions from the combustion of different fuels in the drying furnace, the reader should consult the *Combustion in Boilers* EET Manual.

The major emissions of concern from drying the raw timber using wood boilers is particulate matter (PM_{10}), although other pollutants, particularly carbon monoxide (CO) and listed organic compounds are also emitted. The type and amount of the emissions depend on a number of variables, including the type and composition of the wood or other fuel burnt, type and firing configuration of the boiler, and the degree of fly ash reinjection employed.

The composition of wood waste depends largely on the industry from which it originates. Furniture manufacturing generates a clean, dry wood waste (ie. two to 20 weight percent moisture) which produces relatively low particulate emission levels when properly burned.

Furnace design and operating conditions are particularly important when firing wood waste. Because of the high moisture content that may be present in wood waste, a larger than usual area of refractory surface is often necessary to dry the fuel before combustion. In addition, sufficient secondary air must be supplied over the fuel bed to burn the volatiles that account for most of the combustible material in the waste. When proper drying conditions do not exist, or when secondary combustion is incomplete, the combustion temperature is lowered, and increased PM_{10}, CO, and VOC emissions result. Short-term emissions can fluctuate with significant variations in fuel moisture content.

Fly ash reinjection, which is commonly used with larger boilers to improve fuel efficiency, has a considerable effect on PM_{10} emissions. Because a fraction of the collected fly ash is reinjected into the boiler, the dust loading from the furnace and, consequently, from the collection device increase significantly per unit of wood waste burned. More recent boiler

installations typically separate the collected particulate into large and small fractions in sand classifiers. The smaller particles, mostly inorganic ash and sand, are sent to ash disposal.

The four most common control devices used to reduce PM_{10} emissions from wood-fired boilers are mechanical collectors, wet scrubbers, electrostatic precipitators (ESPs), and fabric filters or baghouses.

Baghouses and ESPs are employed when collection efficiencies above 95 percent are required. However, baghouses have had limited application to wood-fired boilers. The principle drawback to fabric filtration, as perceived by potential users, is a fire danger arising from the collection of combustible carbonaceous fly ash. Steps can be taken to reduce this hazard, including the installation of a mechanical collector upstream of the fabric filter to remove large burning particles of fly ash.

Emissions of nitrogen oxides (NO_x) from wood-fired boilers are lower than those from coal-fired boilers, due to the lower nitrogen content of wood and the lower combustion temperatures, which are a characteristic of wood-fired boilers. Emissions and emission estimation techniques for calculating emissions from wood-fired boilers, and boilers using other fuels, are contained in the *Combustion in Boilers* EET Manual and will not be replicated here.

3.1.2 Machining

The primary emissions from the sawing and planing processes are PM_{10}. Because no coating materials have been applied to the furniture prior to machining, the particles and particulate emissions are almost completely composed of wood, unlike emissions from later sandings which contain particles of finishing material as well as wood particles.

3.1.3 Assembly

Adhesives can be either natural or synthetic in origin and typically contain solvents. Commonly used adhesive formulations contain solvents such as methyl isobutyl ketone, methyl ethyl ketone, xylenes, and toluene. All of these solvents are NPI-listed substances.

Solvents are also used to clean adhesive application equipment such as spray guns. Adhesives used to apply veneer can differ from adhesives used for assembly and usually include phenolics, ureas, melamines, polyvinyl resin emulsions, hot melts, contacts, and mastics. Application of some of these adhesives requires the use of heat and/or pressure. Solvent emissions from the use of adhesives during assembly and veneer application (either as a product carrier or cleaning agent) can be significant.

3.1.4 Pre-Finishing

Typical emissions from the pre-finishing steps are spent solvents from the derosination process and spent bleaching agents from the bleaching process. Derosination entails the application of ammonia and acetone to remove the natural resin in wood. Bleaching agents used by the wood furniture industry include hydrogen peroxide, sodium bisulfate, sodium perborate, oxalic acid, potassium permanganate, and sodium or calcium hypochlorite. Of these basic compounds and mixtures, sodium perborate ($NaBO_3.4H_2O$)

contains the NPI-listed boron and potassium permanganate ($KMnO_4$) the listed metal manganese.

3.1.5 Coating Application

In the wood furniture industry, coatings are usually applied in spray booths, using various types of spray application equipment. The booths generally do not have any temperature or humidity control, and are maintained at ambient conditions. Often, both manual and automatic spray booths are equipped with dry filters, typically a paper material, to control particles. In the past, water curtains had been used to control PM_{10} emissions. However, since the spent waste is disposed of as hazardous waste under most State and Territory licensing regulations, and as hazardous waste disposal costs have increased in recent years, the cost effectiveness of water curtain filtration have decreased. Therefore, most of the new and modified spray booths in the wood furniture industry that use filters are equipped with dry filters. Some water-wash spray booths nevertheless remain in use.

Recirculating a portion of the exhaust from the spray booth increases the concentration of VOCs in the exhaust air leaving the spray booth and discharged to an end-of-pipe control system. During recirculation practices, equal portions of fresh air and recirculated air are pumped back into the booth. One advantage of using recirculation is the decreased exhaust flow volume emitted to the air and decreased capital and operating costs of the VOC control system.

3.1.6 Finishing

The primary emissions of the finishing steps of the manufacturing process include solvent emissions to the air, as well as spent solvents, and particulates consisting of wood and coating materials applied to the furniture. Solvents or thinners used in paints include toluene and xylenes. Rubbing and polishing, performed after finishing, require the use of materials containing lubricants, such as detergents and petroleum-based thin oils, and abrasives, such as pumice, tripoli, and diatomaceous earth. Because wood furniture finishing is a solvent-intensive process, the primary outputs are spent solvents and solvent emissions.

Flashoff areas are areas that can be found either between spray booths, or between a spray booth and an oven, in which solvent is allowed to volatilise from the coated piece. While some flashoff areas have forced air circulation and are referred to as forced-flashoff areas, most flashoff areas do not have a separate exhaust. The length of flashoff areas varies significantly by facility, and even within a facility, depending on whether the coating will be cured in an oven. A flashoff area that is not followed by an oven is often longer than one that is located in between a booth and an oven.

Ovens are used between some coating steps to cure the coating prior to the next step in the finishing sequence. Many types of ovens are used in the wood furniture industry. Most are steam-heated using either a wood or coal-fired boiler; others are gas-fired. Infrared or ultraviolet ovens are also used, but their use in wood furniture manufacturing is currently limited. Oven temperatures can range from less that 38 to 120 °C depending on the type of coating used, the piece being coated, and the oven residence time. The exhaust rate from ovens also varies, and can range between 0.35 and 7 cubic metres per second.

Table 2 contains the relative VOC emissions for three model plants:
(1) a residential furniture manufacturing facility using a long finishing sequence (consisting of a total of three or more stain applications; a single application of wash coat, filler, sealer, and highlight; and two or three topcoat applications);
(2) a residential furniture manufacturing facility using a short finishing sequence (consisting of two stain applications, one application of washcoat and sealer, and two topcoat applications); and
(3) an office/cabinet manufacturing facility using a short finishing sequence (consisting of one application of stain, sealer, and topcoat). The relative VOC emissions are presented as a percent of each coating applied for each model plant.

Table 2 - **Relative VOC Emissions**

Type of Plant	Furniture Long	Furniture Short	Office & Cabinet
Stain	26 percent	28 percent	32 percent
Washcoat	4 percent	4 percent	-
Filler	3 percent	-	-
Wiping stain/glaze	8 percent	-	-
Sealer	18 percent	32 percent	32 percent
Highlight	1 percent	-	-
Topcoat	40 percent	36 percent	36 percent
Total	**100 percent**	**100 percent**	**100 percent**

Source: USEPA Sector Notebook Project, 1995.

3.1.7   Clean-Up Operations

Solvent-borne nitrocellulose lacquers are the predominant type of coatings used by the wood furniture industry today. The resins in such coatings are relatively difficult to dissolve, so a high-solvency-rated solvent must be used in their formulation. Similarly, thinning of these coatings requires the use of the same solvent or one with equivalent solvency. This solvent is generically referred to as *lacquer thinner*. The current practice is to use lacquer thinner for both incidental thinning of premixed coatings and for clean-up of the coatings. Advantages of the lacquer thinner include its compatibility with the finishing materials and the ease with which it removes cured nitrocellulose lacquers.

In wood-coating operations, industrial solvents are used predominantly for cleaning application equipment. In addition, clean-up solvent can also be used to clean out piping, clean booths and rails, strip cured coatings from wood parts or machinery, and periodically clean centralised coating storage and distribution (pump room) equipment.

Application equipment must be cleaned every time there is a colour change, and usually before the equipment is to be idle for a period of time (for example, at the end of the day). For spray coating application, equipment cleaned with solvents includes spray guns, feed lines, and coating reservoirs (where applicable). In the case of roll coating operations, the rollers and spray bar nozzles must also be cleaned periodically to maintain application quality as well as prior to colour changes.

Spray guns have traditionally been cleaned by sending pure solvent from the coating reservoir through the gun, and atomising the solvent into the booth ventilation system.

Recognising that this results in significant emissions of solvent, some operators cut off the atomising air to the spray gun and pump the clean-up solvent through the gun into a container. This procedure can work if the gun is the type that does not depend on the flow of the atomising air to pump the coating (or clean-up solvent) through the mechanism. Alternately, clean-up may involve soaking the entire gun in solvent. This guards against the possibility that small amounts of coating inadvertently missed during the cleaning will cure and clog the small orifices of the gun. Clean-up solvent is often reused within the facility, and eventually recycled in-house or transferred off-site for recycling or disposal.

Table 3 - Inputs and Emissions from Wood Furniture Manufacturing Facilities

Process	Material Input	Atmospheric Emissions	Water Emissions	Emissions to Land
Drying				
Ovens & Kilns	Raw timber	Chemicals used in wood pre-treatment such as CCA (copper-chrome-arsenic)		Wood wastes containing CCA
Machining				
Sawing, Planing, & Sanding	Dried timber	PM_{10}		
Bending and Drying	Timber	Chemicals used in wood pre-treatment		
Assembly				
Gluing & Veneer Application	Hot melts, poly-vinyl acetate, and solvent based adhesives	Solvent emissions (methyl isobutyl ketone, methyl ethyl ketone, xylenes, and toluene)		Spent solvent based adhesives (methyl isobutyl ketone, methyl ethyl ketone, xylenes, and toluene)
Sanding	Assembled furniture	PM_{10}		
Pre-Finishing				
Watering and Sanding	Assembled furniture, resins, and adhesives		Adhesives and resin particles	Adhesives and resin particles
Derosination	Ammonia and acetone	Solvent emissions (eg. ammonia and acetone)	Spent acetone and ammonia	Spent acetone and ammonia
Bleaching	Bleaching agents such as sodium perborate, potassium per-manganate, and calcium or sodium hypo-chlorite		Bleaching agents such as sodium perborate and potassium per-manganate	Bleaching agents such as sodium perborate and potassium per-manganate

Table 3 - Inputs and Emissions from Wood Furniture Manufacturing Facilities (cont')

Process	Material Input	Air Emissions	Water Emissions	Emissions to Land
Finishing				
Staining	Mineral spirits, alcohol, solvents, pigments (lead chromate, iron oxides, cadmium selenide)	Solvent emissions (alcohols including methanol and ethanol, methyl isobutyl ketone, methyl ethyl ketone, xylenes and toluene)		Pigment wastes (lead chromate, cadmium selenide and solvent wastes)
Washcoating	Nitrocellulose-based lacquers, acrylic lacquers, varnish, shellac, polyurethane solvents	Solvent emissions (alcohols, methyl isobutyl ketone, methyl ethyl ketone, xylenes and toluene)		Spent solvents, nitrocellulose-based lacquers, acrylic lacquers, varnish, shellacs
Filling	Pigments (iron oxides, cadmium selenide, lead chromate, calcium sulfate) stains, drying oils, synthetic resins, solvent-based thinners	Solvent emissions (alcohols, acetone methyl isobutyl ketone, methyl ethyl ketone, xylenes and toluene)		Spent solvent, stains, drying oils, synthetic resins, thinners, and pigments (lead chromate, calcium sulfate, cadmium selenide)
Sealing	Nitrocellulose-based lacquers, acrylic lacquers, varnish, shellac, solvents, and polyurethane	Solvent emissions (alcohols, acetone methyl isobutyl ketone, methyl ethyl ketone, xylenes and toluene)		Spent solvents, nitrocellulose-based lacquers, acrylic lacquers, varnish, shellac
Priming	Fungicide, water-repellent			Boron based fungicide wastes

Table 3 - Inputs and Emissions from Wood Furniture Manufacturing Facilities (cont')

Process	Material Input	Air Emissions	Water Emissions	Emissions to Land
Painting	Toluene, acrylic, pigments (lead chromate, iron oxides, titanium dioxide), epoxy-ester resins, vinyl acetate, glycol ethers, and halo-generated hydro-carbons	Solvent emissions particularly toluene and halo-generated hydro-carbons		Spent solvents (toluene), pigments (iron oxides, titanium dioxide, lead chromate) aromatic hydro-carbons, glycol ethers, halo-generated hydro-carbons, vinyl acetate, acrylic
Topcoat Application	Denatured, alcohols, resins, petroleum distil-lates, toluene, diisocyanates	Solvent emissions particularly toluene		Spent denatured alcohols, resins, shellac, toluene, petroleum distill-ates, toluene diisocyanates
Sanding (occurs between each of the finishing stages)	Finished piece of furniture	PM_{10} emissions that include, stain, resin, paint, wood, adhesive, nitrocellulose, lacquer, sealer	Emissions that include, stain, resin, paint, wood, adhesive, nitrocellulose, lacquer, sealer	Waste that includes wood, resin, nitro-cellulose lacquer, paint, stain, filler, and sealer
Rubbing and Polishing	Lubricants, deter-gents, petroleum-based thin oil, tripoli, diatomaceous earth			Spent lubricants, detergents, and oils

Table 3 - Inputs and Emissions from Wood Furniture Manufacturing Facilities (cont')

Process	Material Input	Air Emissions	Water Emissions	Emissions to Land
Clean-up Operations				
Brush Cleaning and Spray gun Cleaning	Acetone, toluene, petroleum, distillates, methanol, dichloromethane, isopropanol, alcohols, mineral spirit	Solvent emissions (acetone, toluene, dichloromethane, methanol)	Spent solvents (acetone, toluene, dichloromethane) methanol, iso-propyl alcohol, ethanol, petroleum distillates	Spent solvents (acetone, toluene, dichloromethane) methanol, isopropanol, ethanol, petroleum distillates
Boilers				
Boilers	Wood and coating material PM from the finishing process	Boiler ash PM_{10}, CO, NO_x, SO_2, and metals		Boiler ash containing listed heavy metals

Source: USEPA Sector Notebook Project, 1995.

3.2   Metal Furniture

The following description of production processes focuses on the emissions of NPI-listed substances arising from metal furniture and fixture surface coating. The emissions of listed substances generated from the foundry, metalworking, and machining sources are covered in the *Ferrous* and *Non-Ferrous Foundries* and *Electroplating and Anodising* EET Manuals. These Manuals, and all NPI Manuals in this series, are available from State and Territory environment agencies. Assembly, pre-finishing, coating application, finishing, and clean-up operations for metal furniture and fixture production, are covered here and emission estimation techniques for these activities are detailed in Section 5.0.

Volatile organic compounds (VOCs) from the evaporation of organic solvents in the coatings are the major NPI pollutants from metal surface furniture surface coating operations. Specific operations that emit VOCs are the coating application process, as well as operations conducted in the flash-off area, and the bake oven. The percentage of total VOC emissions given off at each emission point varies from one installation to another, but on the average spray coating line, about 40 percent is given off at the application station, 30 percent in the flash-off area, and 30 percent in the bake oven.

Factors affecting the quantity of VOCs emitted from metal furniture surface coating operations are the VOC content of the coatings applied, the solids content of coatings applied, and the transfer efficiency. Knowledge of both the VOC content and solids content of coatings is necessary in cases where the coating contains other components, such as water.

The transfer efficiency (volume fraction of the solids in the total consumed coating that remains on the part) varies with the application technique (See Table 4). Transfer efficiency for standard (or ordinary) spraying ranges from 25 to 50 percent. The range for electrostatic spraying, a method that uses an electrical potential to increase transfer efficiency of the coating solids, is from 50 to 95 percent, depending on part size and shape. Powder coating systems normally capture and recirculate overspray material and, therefore, are considered in terms of a *utilisation rate* rather than a transfer efficiency. Most facilities achieve a powder utilisation rate of 90 to 95 percent.

Table 4 - Coating Method Transfer Efficiencies

Application Methods	Transfer Efficiency (TE)[a]
Air atomised spray	0.25
Airless spray	0.25
Manual electrostatic spray	0.60
Nonrotational automatic electrostatic spray	0.70
Rotating head electrostatic spray (manual and automatic)	0.80
Dip coat and flow coat	0.90
Electrodeposition	0.95

Source: USEPA *AP-42*, 1995.
[a]TE is the volume fraction of the solids in the total consumed coating that remains on the part.

Two types of control techniques are available to reduce VOC emissions from metal furniture surface coating operations. The first technique makes use of control devices such as carbon absorbers and thermal or catalytic incinerators to recover or destroy VOCs before they are discharged into ambient air. These control methods are seldom used in the industry, however, because the large volume of exhaust air and low concentrations of VOCs in the exhaust reduce their efficiency. The more prevalent control technique involves reducing the total number of VOCs likely to be evaporated and emitted. This is accomplished by use of low VOC-content coatings and by improvements in the transfer efficiency. New coatings with relatively low VOC levels can be used instead of the traditional high VOC-content coatings. Examples of these new systems include waterborne coatings, powder coatings, and higher solids coatings. Improvements in coating transfer efficiency decrease the number that must be used to achieve a given film thickness, thereby reducing emissions of VOCs to the ambient air. By using a system with increased transfer efficiency, (such as electrostatic spraying), and lower VOC content coatings, VOC emission reductions can approach those achieved with control devices.

Section 5.0 presents emission factors for estimating VOC emissions from metal furniture surface coating.

4.0   Emission Estimation Techniques: Acceptable Reliability and Uncertainty

Several techniques are available for calculating emissions of NPI-listed substances from furniture and fixture manufacturing operations. The best emission estimation technique (EET) to use depends on the emission source being evaluated, available data, available resources, and the degree of accuracy required by the facility in conducting the estimate. Emissions to the air, water and land are likely to be the primary emission points to consider. If water is treated on-site, sludges or other wastes containing listed substances may be created. Other emissions may come from discarded containers or samples, vessel washings, or from volatilisation to the air. Facility operators should ensure that all emissions are accounted for when reporting.

In general, there are four types of EETs for calculating emissions from furniture and fixture manufacturing activities:

- emission factors;
- fuel analysis or engineering calculations;
- mass balance; and
- sampling or direct measurement.

If you estimate your emission by using any of these EETs, your data will be displayed on the NPI database as being of 'acceptable reliability'. Similarly, if your relevant environmental authority has approved the use of EETs that are not outlined in this handbook, your data will also be displayed as being of 'acceptable reliability'.

This Manual seeks to provide the most effective emission estimation techniques for the NPI substances relevant to this industry. However, the absence of an EET for a substance in this handbook does not necessarily imply that an emission should not be reported to the NPI. The obligation to report on all relevant emissions remains if reporting thresholds have been exceeded.

> **You are able to use emission estimation techniques that are not outlined in this document. You must, however, seek the consent of your relevant environmental authority. For example, if your company has developed site-specific emission factors, you may use these if approved by your relevant environmental authority.**

You should note that the EETs presented in this manual relate principally to average process emissions. Emissions resulting from non-routine events are rarely discussed in the literature, and there is a general lack of EETs for such events. However, it is important to recognise that emissions resulting from significant operating excursions and/or accidental situations (eg. spills) will also need to be estimated. Emissions to land, air and water from spills must be estimated and added to process emissions when calculating total emissions for reporting purposes. The emission resulting from a spill is the net emission, ie. the quantity of the NPI reportable substance spilled, less the quantity recovered or consumed during clean up operations.

The **usage** of each of the substances listed as Category 1 and 1a under the NPI must be estimated to determine whether the 10 tonnes (or 25 tonnes for VOCs) reporting threshold is exceeded. If the threshold is exceeded, **emissions** of these Category 1 and 1a substances must be reported for all operations/processes relating to the facility, even if the actual emissions of the substances are very low or zero.

4.1   Emission Factors

An emission factor can be defined as a pollutant emission rate relative to a level of source activity. Emission factors are generally based on the results of source tests performed at one or more facilities within the same or similar industries.

Emission factors for furniture and fixture manufacturing processes are provided in Section 5.0. Using site-specific emission factors is more cost-effective than collection and analysis of air and water samples or the use of engineering calculations.

The reader should recognise that, in most cases, emission factors adopted for the NPI are averages of available industry-wide data with varying degrees of quality. Emission factors are, however, an acceptable technique for estimating emissions for the NPI where estimations of emissions are required to quantify medium to long-term emission trends.

Every emission factor has an associated emission factor rating (EFR) code. This rating system is common to EETs for all industries and sectors and therefore, to all Industry Handbooks. They are based on rating systems developed by the United States Environmental Protection Agency (USEPA), and by the European Environment Agency (EEA). Consequently, the ratings may not be directly relevant to Australian industry. Sources for all emission factors cited can be found in Section 6.0 of this Manual. The emission factor ratings will not form part of the public NPI database.

When using emission factors, you should be aware of the associated EFR code and what that rating implies. An A or B rating indicates a greater degree of certainty than a D or E rating. The less certainty, the more likely that a given emission factor for a specific source or category is not representative of the source type. These ratings notwithstanding, the main criterion affecting the uncertainty of an emission factor remains the degree of similarity between the equipment/process selected in applying the factor, and the target equipment/process from which the factor was derived.

The EFR system is as follows:

A   -   Excellent
B   -   Above Average
C   -   Average
D   -   Below Average
E   -   Poor
U   -   Unrated

4.2   Engineering Calculations

Theoretical and complex equations or *models* can be used for estimating emissions from furniture and fixture manufacturing processes. EET equations are available for the following types of emissions found at a furniture manufacturing facility:

- material loading;
- surface evaporation;
- material storage; and
- spills.

Inputs for theoretical equations generally fall into the following categories;
(1) chemical/physical properties of the material involved, such as vapour pressure and vapour molecular weight;
(2) operating data, such as the amount of material processed and operating hours; and
(3) physical characteristics and properties of the source, such as tank colour and diameter.

Use of emission equations to estimate emissions from furniture manufacturing facilities is a more complex and time-consuming process than the use of emission factors. Emission equations require more detailed inputs than the use of emission factors, but they do provide an emission estimate that is based on facility-specific conditions.

4.3   Mass Balance

A mass balance approach may be used to estimate emissions when the quantities of a material used, recycled, emitted, and disposed of are known. Emissions from a furniture manufacturing facility can be estimated through knowledge of the amounts of VOCs purchased as solvent in coatings and the amounts recycled or otherwise sent off-site for disposal. The difference is assumed to have been emitted to the air on-site as only negligible amounts remain on coated product. Solvent usage figures would generally be in litres.

Similarly, estimating emissions for speciated VOCs would require knowledge of the types of solvents used and the weight percentages of NPI-listed materials in the solvents. Annual usage may be based on gross purchase amount (in liters). When operations have several formulas for different batches or product runs, a conservative emissions estimate for each listed substance may be estimated based on the formula with the highest listed substance usage. This approach is suitable for speciated organics (xylenes, toluene) because they are not involved in chemical reactions and their usage rates may already be tracked for purchasing reasons or for workplace health and safety procedures.

4.4   Direct Measurement

Because vent or other outlet testing is relatively uncommon for Australian furniture manufacturing facilities, emissions test data for these facilities are generally only available in the form of monitoring results for NPI-listed substances conducted for compliance with Worksafe Australia Exposure Standards for Atmospheric Contaminants in the Workplace Environment. However, while these data may be used in conjunction with exhaust system flow rates to calculate total PM_{10}, VOC, or speciated organic solvent emissions from a room, floor, or building, emissions are often below reliable detection limits due to high flow rates and low concentrations of the pollutants of interest.

5.0   Estimating Emissions

An effective means of evaluating points of emission for listed substances is to draw a process flow diagram identifying the operations performed at a reporting facility. Figure 1 below is an example flow diagram for a furniture surface coating line. Because each facility is unique, facilities reporting to the NPI are strongly urged to develop flow diagrams for their own particular operations that detail the input of materials and listed substances and the emissions sources resulting from the operation of each unit.

Emissions to the air, water and land are likely to be the primary emission points to consider. If water is treated on-site, sludges or other wastes containing listed substances may be created. Other emissions may come from discarded containers or samples, vessel washings, or, for some substances, volatilisation to the air. Facility operators should ensure that all emissions are accounted for when reporting.
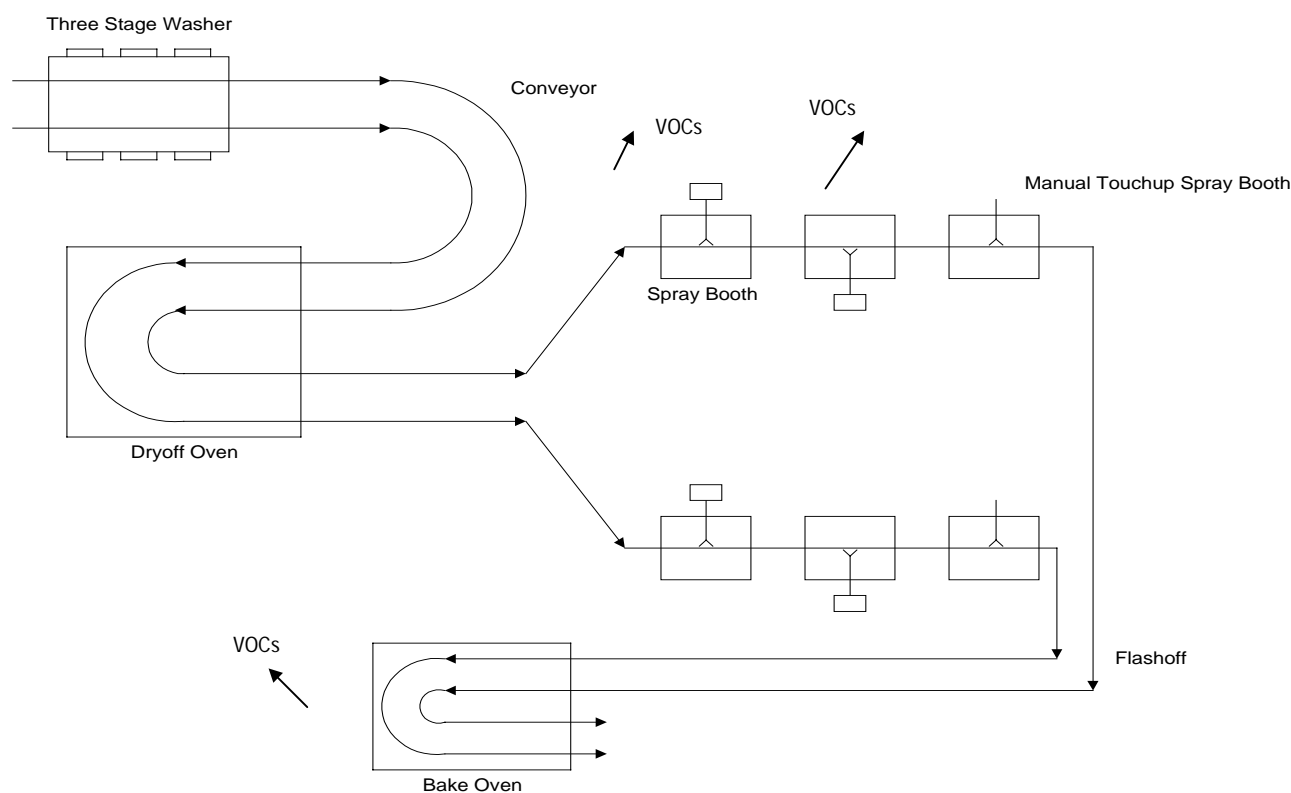
Figure 1 - **Example of an Automated Furniture Spray Coating Line**
Source: Queensland Department of Environment and Heritage, 1998.

After all the listed substances and emission sources at the reporting facility have been identified, the procedures for estimating emissions can proceed. The usual approach entails first estimating emissions from emission sources across a facility for all substances triggering a threshold and then, based on the disposal method used, determining whether emissions from a particular emission source are to air, water, land, or to an off-site disposal facility. (The off-site transfer of listed substances, including listed substances contained in wastes, does not require reporting, but may still need to be determined when conducting a mass balance to estimate emissions).

5.1   Sampling Data

Stack sampling test reports often provide emissions data in terms of kg per hour or grams per cubic metre (dry standard). Annual emissions for NPI reporting can be calculated from this data. Stack tests for NPI reporting should be performed under representative (ie. normal) operating conditions. You should be aware that some tests undertaken for a State or Territory license condition may require the test be taken under maximum emissions rating, where emissions are likely to be higher than when operating under normal operating conditions.

Calculations involved in determining PM_{10} emissions are used as an example, although the same calculations are applicable for most NPI-listed substances emitted from stack sources.

An example summary of a test method is shown in Table 5. The table shows the results of three different sampling runs conducted during one test event. The source parameters measured as part of the test run include gas velocity and moisture content, which are used to determine exhaust gas flow rates in cubic metres per second (m^3/sec). The filter weight gain is determined gravimetrically and divided by the volume of gas sampled (as shown in Equation 1) to determine the particulate matter (PM) concentration in grams per cubic metre (g/m^3).

Equation 1

$$C_{PM} = C_f \ / \ V_{m, STP}$$

where:

C_{PM} = concentration of PM or gram loading, g/m^3
C_f = filter catch, g
$V_{m,STP}$ = metered volume of sample at STP, m^3

Equation 2

$$E_{PM} = C_{PM} * Q_d * 3.6 * [273/(273 + T)]$$

where:

E_{PM} = hourly emissions of PM, kg/hr
C_{PM} = concentration of PM or gram loading, g/m^3
Q_d = stack gas volumetric flow rate, m^3/sec
T = stack temperature, ^{o}C

Table 5 - Stack Sample Test Results

Parameter	Symbol	Test 1	Test 2	Test 3
Total sampling time (sec)		7 200	7 200	7 200
Moisture collected (g)	g_{MOIST}	395.6	372.6	341.4
Filter catch (g)	C_f	0.0851	0.0449	0.0625
Average sampling rate (m³/s)		$1.67 * 10^{-4}$	$1.67 * 10^{-4}$	$1.67 * 10^{-4}$
Standard metered volume (m³)	$V_{m, STP}$	1.185	1.160	1.163
Volumetric flow rate (m³/s), dry	Q_d	8.48	8.43	8.45
Concentration of particulate (g/m³)	C_{PM}	0.0718	0.0387	0.0537

Source: Queensland Department of Environment and Heritage, 1998.

Example 1 illustrates the application of Equation 1 and Equation 2 and the sampling test data from Table 5.

Example 1 - Using Sampling Data

PM emissions calculated using Equation 1 and Equation 2 and the stack sampling data for Test 1 (presented in Table 5), and an exhaust gas temperature of 150°C (423K)), are shown below:

$$C_{PM} = C_f / V_{m, STP}$$
$$= 0.0851 / 1.185$$
$$= 0.072 \text{ g/m}^3$$

$$E_{PM} = C_{PM} * Q_d * 3.6 * [273/(273+T)]$$
$$= 0.072 * 8.48 * 3.6 (273/423K)$$
$$= 1.42 \text{ kg/hr}$$

The information from some stack tests may be reported in grams of particulate per cubic metre of exhaust gas (wet). Use Equation 3 to calculate the dry particulate emissions in kg/hr.

Equation 3

$$E_{PM} = Q_a * C_{PM} * 3.6 * \left(1 - moist_R \Big/ 100\right) * \left[273 \Big/ (273 + T)\right]$$

where:

E_{PM}	=	hourly emissions of PM in kilograms per hour, kg/hr
Q_a	=	actual (ie. wet) cubic metres of exhaust gas per second, m³/s
C_{PM}	=	concentration of PM or gram loading, g/m³
3.6	=	3600 seconds per hour multiplied by 0.001 kilograms per gram
$moist_R$ =		moisture content, %
273	=	273 K (0°C)
T	=	stack gas temperature, °C

Total suspended particulates (TSP) are also referred to as total particulate matter (total PM). To determine PM_{10} from total PM emissions, a size analysis may need to be undertaken. The weight PM_{10} fraction can then be multiplied by the total PM emission rate to produce PM_{10} emissions. Alternatively, assume that 100% of PM emissions are PM_{10}; ie assume that all particulate matter emitted to air has an equivalent aerodynamic diameter of 10 micrometres or less ie. $\leq 10\mu m$.

To calculate moisture content use Equation 4.

Equation 4

Moisture percentage = 100 % * weight of water vapour per specific volume of stack gas / total weight of the stack gas in that volume.

$$moist_R = \frac{100\% * \left(\frac{g_{moist}}{(1000 * V_{m,STP})}\right)}{\left(\frac{g_{moist}}{(1000 * V_{m,STP})}\right) + \rho_{STP}}$$

where

$moist_R$ =	moisture content, %	
g_{moist} =	moisture collected, g	
$V_{m,STP}$ =	metered volume of sample at STP, m3	
ρ_{STP} =	dry density of stack gas sample, kg/m3 at STP	
	{if the density is not known a default value of 1.62 kg/m3 may be used. This assumes a dry gas composition of 50% air, 50% CO_2}	

Example 2 – Calculating Moisture Percentage

A 1.2m^3 sample (at STP) of gas contains 410g of water. To calculate the moisture percentage use **Error! Reference source not found.**.

$$moist_R = \frac{100\% * \left(\frac{g_{moist}}{(1000 * V_{m,STP})}\right)}{\left(\frac{g_{moist}}{(1000 * V_{m,STP})}\right) + \rho_{STP}}$$

$g_{MOIST}/1000 * V_{m,STP}$ =	410 / (1000 * 1.2)	
=	0.342	
$moist_R$ =	100 (0.342 / 0.342 + 1.62)	
=	17.4%	

5.2 Calculating Emissions from Paint and Solvent Usage to Air

Painting operations emit VOCs to the air through evaporation of the paint vehicle, thinner, or solvent used to facilitate the application of the coatings. The main factor affecting VOC emissions from painting operations is the volatile content of the coatings, which averages around 15 percent for water-based coatings and over 50 percent for solvent-based coatings. Most, if not all, of the volatile portion of the coating evaporates during or following application. To reduce these emissions, paint manufacturers have reduced the VOC content of coatings in recent years. In addition, air pollution control equipment, such as activated carbon adsorption of hydrocarbon emissions or destruction of hydrocarbons in an afterburner, is available for use in some applications. To calculate emissions from paint and solvent usage to air using the mass balance method a series of complex equations would be needed.

5.2.1 From Wood Furniture and Fixture Manufacturing

Emissions

The technique for calculating VOC emissions from painting operations is quite straightforward. For each type of coating fluid used in painting, the quantity of coating used is multiplied by the VOC content of the coatings to obtain the total VOC emissions from the use of that coating. If any type of air pollution control equipment is used, the VOC emissions estimate is reduced by the effectiveness of the equipment to reflect the effects of the control device. To report emissions of speciated VOCs, such as toluene or xylenes, the same method is used with the quantity of coating used being multiplied by the individual content of the substance being inventoried. The technique is expressed by Equation 5.

Equation 5

$$E_{kpy,VOC} = \Sigma [Q_i * (VOC_i/100) * \rho * (1 - CE / 100)]$$

where:

$E_{kpy,VC}$ = total emissions of VOCs from painting operations, kg/yr
Q_i = total quantity of coating type i used in the reporting year, L/yr
VOC_i = VOC type i content for coating, weight percent
ρ = density of coating (eg. paint, varnish etc), kg/L
CE = control efficiency of afterburner or other emission abatement equipment, %
i = coating type (paint, varnish, shellac, lacquer, enamel, primer)

Example 3 illustrates the application of Equation 4.

Example 3 - **Estimating VOC Emissions from Furniture and Fixture Painting**

Purchasing records show that a furniture manufacturer consumed 9 300 litres of one particular type of primer during the reporting year. The MSDS for the primer indicates that its density is 1kg/L, and that it contains 28 percent by weight toluene and 54 percent by weight methyl ethyl ketone (MEK). The facility operator estimates that 80 percent of the primer was used on furniture in a paint booth with an afterburner fitted which typically destroys 98 percent of VOCs. The remaining 20 percent was applied outside the booth during retouching. Emissions can be estimated using Equation 5.

$$Q \qquad = \qquad 9\ 300\ L/yr$$
$$VOC_{toluene} \qquad = \qquad 28\ \%$$
$$VOC_{MEK} \qquad = \qquad 54\ \%$$
$$\rho \qquad = \qquad 1kg/L$$
$$CE \qquad = \qquad 98\ \%$$

$$
\begin{aligned}
E_{kpy,toluene} \quad &= \quad \Sigma\ [Q_i * VOC_i * (1 - CE\ /\ 100)] \\
&= \quad [(9\ 300 * 80/100) * 28/100 * 1 * (1 - 98/100)] + \\
&\qquad [(9\ 300 * 20/100) * 28/100 * 1 * (1 - 0/100)] \\
&= \quad [(2\ 083) * (1 - 98/100)] + [(521) * (1 - 0/100)] \\
&= \quad 563\ kg\ toluene/yr
\end{aligned}
$$

$$
\begin{aligned}
E_{kpy,MEK} \quad &= \quad \Sigma\ [Q_i * VOC_i * (1 - CE\ /\ 100)] \\
&= \quad [(9\ 300 * 80/100) * 54/100 * 1 * (1 - 98/100)] + \\
&\qquad [(9\ 300 * 20/100) * 54/100 * 1 * (1 - 0/100)] \\
&= \quad [(4\ 018) * (1 - 98/100)] + [(1\ 004) * (1 - 0/100)] \\
&= \quad 1\ 084\ kg\ MEK/yr
\end{aligned}
$$

$$
\begin{aligned}
E_{kpy,VOC} \quad &= \quad E_{kpy,toluene} + E_{kpy,MEK} \\
&= \quad 563 + 1\ 084 \\
&= \quad 1\ 647\ kg\ VOC/yr
\end{aligned}
$$

Painting and Coating Emissions - Data Inputs

To estimate total and speciated VOC emissions from painting activities at wood furniture and fixture manufacturers, four data inputs are required: the type of coating used, the quantity of coating used, an uncontrolled emission factor, and an air pollution control efficiency factor (if applicable). Coatings include paint, varnish and shellac, lacquer, enamel, and primer. Purchasing records should be able to provide information on the type of coatings used and the paint manufacturer details on the VOC content and VOC speciation profile of coating products used during the reporting year.

The quantities of each type of coating used are usually available in litres. Material and Safety Data Sheets (MSDS) or paint and coating manufacturers and suppliers should be consulted to obtain the volatile content, expressed in terms of kilograms per litre of organic solvent or VOC. If ranges of VOC content only are provided, then the range mid-

point should be selected. If VOC content for a specific product type is not available, the default values in Table 6 should be used.

Table 6 - VOC Content of Common Surface Coatings

Surface Coating	VOC Content (kg/L)
Paint (solvent based)	0.672
Paint (water based)	0.156
Enamel	0.420
Lacquer	0.732
Primer	0.792
Varnish and Shellac	0.396
Thinner	0.883
Adhesive	0.528

Source: Queensland Department of Environment and Heritage, 1998.

Air pollution emission control equipment, such as activated carbon adsorption or afterburner destruction of the vapours, is sometimes used in painting operations. Information on the demonstrated effectiveness of these control methods can be obtained from the maintenance section or from the equipment manufacturer, before calculating emissions for NPI reporting.

Solvent Emissions

The use of organic solvents, such as chlorinated hydrocarbons, petroleum distillates, ketones, and alcohols, results in the evaporation of VOCs and other speciated organic compounds, which are emitted to the air. If water-based alkaline wash systems are used for degreasing, no evaporation of VOCs or other organic compounds listed on the NPI will occur.

The techniques for estimating evaporative VOC (both total and speciated) emissions from the operation of solvent degreasers is presented below. The techniques are based on the assumption that all solvent consumed by a solvent degreasing unit is either disposed of as waste liquid (either on-site or transferred off-site to landfill or wastewater treatment plant) or emitted to the air from the furniture manufacturing facility. The emissions to the air, therefore, are simply estimated by calculating the difference between the volume of solvent consumed and the volume of solvent disposed of as liquid, and multiplying the difference by the density of the solvent. This mass balance technique is expressed by Equation 6, which calculates the total VOC emissions for one solvent degreaser.

Equation 6

$$E_{kpy,VOC} = \rho * (QC - QD)$$

where:

$E_{kpy,VOC}$ = VOC emissions from solvent degreasing unit, kg/yr

QC = volume of solvent consumed in solvent degreaser, L/yr

QD = volume of solvent disposed of as a liquid, L/yr

ρ = density of solvent, kg/L

Solvent Emissions - Data Inputs

The quantity of solvent consumed throughout the NPI reporting period, expressed in litres, should be available from purchasing records or from the operator of the solvent degreaser being inventoried. The quantity of solvent disposed of as liquid, expressed in litres, should also be available from the solvent degreaser, particularly if the waste is disposed of as hazardous waste. If no records on solvent disposal are available, then it should be assumed, for NPI reporting purposes, that 100 percent of the solvent consumed by the solvent degreaser is emitted to the air as a VOC emission.

The density of the solvents being used is available from the operator of the solvent degreaser, from the solvent manufacturer or distributor, or, if product specific information is not available from these sources, the default values from Table 7 should be used for NPI reporting purposes. Density should be expressed as kilograms per litre.

Table 7 - Density of Common Solvents Used in Solvent Degreasers

NPI-Listed Solvent	Density (kg/L)
Acetone	0.792
Ethanol	0.792
Methanol	0.810
Chloroform	1.491
Dichloromethane (methylene chloride)	1.328
Tetrachloroethylene (perchloroethylene)	1.625
Trichloroethylene	1.466

Source: Queensland Department of Environment and Heritage, 1998.

5.2.2 From Metal Furniture and Fixture Manufacturing

The technique for calculating VOC emissions from metal furniture and fixture painting operations is quite straightforward. The technique is expressed by Equation 7.

Equation 7

$$E_{VOC} = (6.45 * 10^{-4} * A * T * V * \rho) \,/\, (S * TE)$$

where:

E_{VOC}	=	emissions of VOCs, kg/hr
A	=	surface area coated, m^2/hr
T	=	dry film thickness of coating applied, mm
V	=	VOC content of coating, including thinning solvents added at the facility, fraction by volume
ρ	=	VOC density, assumed to be 0.88 kg/L for total VOCs
S	=	solids content of coating, fraction by volume
TE	=	transfer efficiency, fraction
$6.45 * 10^{-4}$	=	constant, converts volume of dry film applied per m^2 to litres

Nominal values for T, V, S, and TE are:

T	=	1 mm (for all cases)
V	=	0.65 (uncontrolled emissions), 0.35 (65 volume % high solids coating), 0.117 (waterborne coating)
S	=	0.35 (uncontrolled emissions), 0.65 (65 volume % high solids coating), 0.35 (waterborne coating)
TE	=	0.65 (for all cases)

The data presented in Table 8 and Table 9 is representative of values which may be obtained from metal furniture manufacturing facilities with similar operating characteristics. These values can be used in applying Equation 7 where site-specific information is unavailable. However, as mentioned in earlier sections, most Australian metal furniture and fixture manufacturers have their own combination of coating formulations, application equipment, operating parameters, and factory configurations and it is recommended, wherever possible, that plant-specific values be obtained for all variables when undertaking emission estimates for NPI reporting.

Table 8 - **Operating Parameters for Coating Operations**

Plant Size	Operating Hours (hr/yr)	Number of Lines	Line Speed [a] (m/min)	Surface Area Coated (m²/yr)	Litres of Coating Used [b]
Small	2 000	1 (1 spray booth)	2.5	45 000	5 000
Medium	2 000	3 (3 booths/line)	2.4	780 000	87 100
Large	2 000	10 (3 booths/line)	4.6	4 000 000	446 600

Source: USEPA *AP-42*, 1995.

[a] Line speed is not used to calculate emissions, only to characterise plant operations and assist reporting facilities.

[b] Using 35 volume % solids coating, applied by electrostatic spray at 65% transfer efficiency.

Table 9 - **Emission Factors for VOCs from Surface Coating Operations**

Plant Size and Control Techniques	VOC Emissions [a,b]		
	kg/m² coated	kg/yr	kg/hr
Small			
Uncontrolled emissions	0.064	2 875	1.44
65 Volume % high solids coating	0.019	835	0.42
Waterborne coating	0.012	520	0.26
Medium			
Uncontrolled emissions	0.064	49 815	24.90
65 Volume % high solids coating	0.019	14 445	7.22
Waterborne coating	0.012	8 970	4.48
Large			
Uncontrolled emissions	0.064	255 450	127.74
65 Volume % high solids coating	0.019	74 080	37.04
Waterborne coating	0.012	46 000	23.00

Source: USEPA *AP-42*, 1995.

[a] **Calculated using the parameters given in**

Table 8 and Equation 7. Values have been rounded off.

Example 4 illustrates the application of Equation 7 and the parameters from Table 9.

Example 4 - **Calculating VOC Emissions from Metal Furniture Coating**

The total VOC emissions from a medium-size plant applying 35 volume % solids coatings can be calculated using Equation 7 and the parameters given in Table 9. The surface area coated is 390 m^2/hr.

$$A = 24.9 \text{ kg/hr}/0.064 \text{ kg/m}^2 = 390 \text{ m}^2/\text{hr}$$

$$E_{VOC} = (6.45 * 10^{-4} * A * T * V * D) \ / \ (S * TE)$$
$$(6.45 * 10^{-4}) * (390 \text{ m}^2/\text{hr}) * (1 \text{ mm}) * (0.65) *$$
$$(0.88 \text{ kg/L})/((0.35) *(0.65))$$
$$= 0.633 \text{ kg VOC/hr}$$

Assume the facility operates for 1 500 hours per year.

$$E_{kpy,VOC} = 0.633 \text{ kg VOC/hr} * 1 \ 500 \text{ hr/yr}$$
$$= 949 \text{ kg VOC/yr}$$

Equation 7 above is suitable for estimating total VOC emissions from metal furniture and fixture coating operations. To report emissions of speciated VOCs, such as toluene or xylenes, the same technique is used with the quantity of coating used being multiplied by the individual content of the substance being inventoried. Equation 8 can be applied to determine speciated VOC emissions from total VOCs emitted.

Equation 8

$$E_{kpy,i} = E_{VOC} * C_i \ /100$$

where:

$E_{kpy,i}$ = emissions of VOC species i, kg/yr
E_{VOC} = total VOC emissions calculated using Equation 6, kg/yr
C_i = proportion of VOC species i in total VOC, mass %

Another technique that may also be used to estimate emissions for metal coating operations involves a mass balance approach. By assuming that all VOCs in the coatings applied are evaporated at the facility site, an estimate of emissions can be calculated using only the coating formulation and data on the total quantity of coating used in the NPI reporting year. The percentage of VOC solvent, and speciated organics, in the coating, multiplied by the quantity of coating used throughout the reporting year yields the total emissions. This method of emissions estimation avoids the requirement to use variables such as coating thickness and transfer efficiency, which are often difficult to define precisely across all the coating operations of a reporting facility.

5.3 Calculating Emissions to Air from Storage Tanks

Table 10 shows the pathways for VOC emissions from three types of organic liquid storage tanks commonly found at large furniture and fixture manufacturing facilities.

As the table indicates, there are a number of pathways for evaporated VOCs to escape from organic liquid storage tanks and enter the air. Accurate calculation of emissions escaping through each of these pathways requires information on the tank structure, fuel type, meteorology, and operating practices. In general, fixed-roof tanks tend to be older and result in the greatest atmospheric emissions.

Table 10 - **Pathways for VOC Emissions to Air from Organic Liquid Storage Tanks**

Tank Type	Standing Storage Emissions	Working Emissions
Fixed Roof	**Breathing Emissions**: Changes in temperature or pressure cause an imbalance between internal and external vapour pressures. Breather valves are opened to equalise pressure, allowing emission of evaporated VOCs.	**Displacement Emissions**: During tank filling, liquid displaces gas inside the tank, forcing it to be expelled through the breather valve. **Air Saturation Emissions**: During fuel removal, air drawn into the tank becomes saturated with VOCs and expands, thus causing an imbalance of vapour pressure with the atmosphere. This imbalance is relieved by venting to the atmosphere.
External Floating Roof	**Rim Seal, Roof Fitting Emissions**: Emissions occur from rim seals and roof fittings due to slight imbalances in internal and external vapour pressure. Exposure of the floating roof to the wind increases emission rates.	**Clingage Emissions**: As the roof is lowered during withdrawal, organic liquid clings to the tank walls and evaporates when exposed to the atmosphere. Evaporation rate increases with wind speed.
Internal Floating Roof	**Rim Seal, Deck Fitting, Deck Seam Emissions**: Emissions occur from rim seal, deck fitting, and deck seam due to slight imbalances in internal and external pressures. Lower emissions occur because the roof is protected from the wind.	**Clingage Emissions**: As the roof is lowered during withdrawal, organic liquid clings to the tank wall and evaporates. Wind does not increase the evaporation rate.

Adapted from: Energy and Environmental Analysis Inc, 1995.

The presence of a volume of vapour space above the level of liquid in the tank promotes evaporation of the fuel VOCs and their subsequent emission to the air through the breather valve. Tanks equipped with a floating roof are able to reduce evaporative emissions by eliminating the vapour space between the liquid level in the tank and the tank roof. However, some emissions do occur through various seals and openings and also because organic liquid clings to the tank walls as the liquid level and roof are lowered.

A technique for estimating the sum of VOC emissions from above-ground and below-ground organic liquid storage tanks is given in the *Fuel and Organic Liquid Storage* EET Manual. A wide range of storage tanks is covered in this document, including fixed roof, internal floating roof, external floating roof, variable vapour space, and pressure tanks. The general methodology is to identify each of the major pathways for VOCs to escape from storage tanks to the air, and use available information to estimate emissions through each pathway. An overview of information requirements is given below. The two main categories of emissions are standing storage emissions, which result from changes in the surrounding temperature and barometric pressure, and working emissions, which result from the loading or withdrawal of liquids such as furniture paints, thinners, and solvents. In both cases, emissions result from higher pressure inside the tank than outside, causing the hydrocarbon vapour, containing VOCs, to escape through any available opening. Depending on the tank type, these openings or pathways include breather vents, rim seals, deck fittings, and deck seams.

The general methodology for calculating storage tank VOC emissions may be expressed by Equation 9.

Equation 9

$$E_{kpy,VOC} = E_S + E_W$$

where:

$$
\begin{aligned}
E_{kpy,VOC} &= \text{total VOC emissions from a single tank, kg/yr} \\
E_S &= \text{standing storage emissions from the tank, kg/yr} \\
E_W &= \text{working emissions from the tank, kg/yr}
\end{aligned}
$$

The techniques for estimating E_S and E_W are different for each tank type. These techniques are described in the *Fuel and Organic Liquid Storage* EET Manual.

Storage Tank Emissions - Data Inputs

A number of data sources are required for an accurate assessment of standing storage and working emissions from organic liquid storage tanks. These include the type of tank, physical dimensions of the tank, fuel type, climatic data, rate of fuel throughput, and other tank-specific characteristics. Detailed information on data requirements is given in the *Fuel and Organic Liquid Storage* EET Manual and an overview of these requirements and the likely sources of this information is given in the following paragraphs.

- **Type of Storage Tank** - The three most common main types of fuel storage tanks are fixed roof, external floating roof, and internal floating roof tanks. Descriptions of the different tank types is given in the *Fuel and Organic Liquid Storage* EET Manual.

- **Organic Liquid Type** - Liquid vapour pressure and density for each storage tank are required to calculate emission losses. Specification of the type of liquids stored in the tank allows for the use of default values for vapour pressure and density in the *Fuel and Organic Liquid Storage* EET Manual.

- **Climatic Data** - Average wind speed, average daily ambient temperature range, average daily solar insulation, and average atmospheric pressure values are each required for the emission calculations. The *Fuel and Organic Liquid Storage* EET Manual contains the necessary climatic data for most Australian cities and towns where larger furniture manufacturers are located. If an facility that is required to report is located in a city or town where climatic data is not specified, the closest nearby city, or city with similar climatic conditions, needs to be specified by the user.

- **Liquid Throughput** - An estimate of annual liquid throughput for each tank needs to be obtained for the July to June reporting year.

- **Tank-Specific Characteristics** - Tank-specific characteristics used in calculating emission losses include one or more of the following: physical dimensions of the tank, type of seals, breather vent settings, tank paint colour, number of vacuum breakers, number of columns, effective column diameter, deck fitting types, and deck seam length. This information can be obtained from the tank manufacturer or distributor or by visual inspection of the tank. In many cases, default values are given in the *Fuel and Organic Liquid Storage* EET Manual.

5.4   Calculating Emissions to Water

Because of the significant environmental hazards posed by emitting toxic substances to water, most facilities emitting listed NPI-listed substances to waterways are required by their relevant State or Territory environment agency to closely monitor and measure these emissions. This existing monitoring data can be used to calculate annual emissions by the use of Equation 10.

Equation 10

$$E_{kpy,i} \quad = \quad C_i * V * OpHrs \, / \, 1\,000\,000$$

where:

$$
\begin{aligned}
E_{kpy,i} \quad &= \quad \text{emissions of pollutant i, kg/yr} \\
C_i \quad &= \quad \text{concentration of pollutant i in wastewater,} \\
&\qquad \text{mg/L} \\
V \quad &= \quad \text{hourly volume of wastewater, L/hr} \\
OpHrs \quad &= \quad \text{operating hours per year for which data apply,} \\
&\qquad \text{hr/yr} \\
1\,000\,000 \quad &= \quad \text{conversion factor, mg/kg}
\end{aligned}
$$

In applying Equation 10 to water emission calculations, monitoring data should be averaged and only representative concentrations used in emission calculations. The total emissions of a listed substance should equal the amount used during the year minus the amount incorporated into products minus the amounts destroyed in on-site treatment and transferred off-site for disposal by another facility. In estimating emissions, it is particularly helpful to first estimate the amount incorporated into the furniture product, or other end-products, before proceeding to individual emission estimates, as this will provide a useful reference point.

If no wastewater monitoring data exists, emissions to process water can be calculated based on a mass balance of the process, shown by Equation 11.

Equation 11

$$E_{kpy,i} = \text{Amount in}_i - \text{Amount out}_i$$

where:

$E_{kpy,i}$ = emissions of pollutant i, kg/yr
Amount in$_i$ = amount of pollutant i entering the process, kg/yr
Amount out$_i$ = amount of pollutant i leaving the process as a waste
stream, article or product, kg/yr

The term "Amount out$_i$" may actually involve several different fates for an individual pollutant. This could include the amount recovered or recycled, the amount leaving the process in the manufactured product, the amount leaving the process in wastewater, or the amount of material transferred off-site as hazardous waste or to landfill. A thorough knowledge of the different fates for the pollutant of interest is necessary for an accurate emission estimate to be made using the mass balance approach.

Where a furniture manufacturing facility uses a listed mineral acid or base, but this acid or base is effectively neutralised in use or during wastewater treatment (to a pH of 6 to 8, as required by most State and Territory effluent standards), no emission quantities should be reported. However, if the acid or base is itself transformed into another listed substance, the quantity of this substance coincidentally produced must be determined to assess if a threshold value has been reached. For example, sulfuric acid often yields hydrogen sulfide in effluent streams, which is a listed substance.

5.5   Calculating Emissions to Land

Wastewater treatment may precipitate the reportable listed substance to a sludge. Facilities are often required to obtain data on the concentration of metals or and other substances in sludges as part of their licensing requirement and this data can be used to calculate the emissions as kilograms of sludge multiplied by the concentrations of the substance in the sludge. Alternatively, the loss in the sludge can be estimated by Equation 12. Although, listed substances in sludges transferred off-site do not require reporting, determining this loss can assist with determining other process losses or may require reporting if the sludge is disposed of on-site.

Equation 12

$$E_{kpy,i} = [Q_{in} * C_{in} - Q_{pr} * C_{pr} - Q_{rec} * C_{rec} - Q_{waste} * C_{waste}] / 10^6$$

where:

$E_{kpy,i}$	=	emissions of pollutant i, kg/yr
$Q_{in}, Q_{pr}, Q_{rec}, Q_{waste}$	=	quantity of raw material, product, recycled material or waste respectively, that is processed annually (generally expressed in kg for solids, L for liquids)
$C_{in}, C_{pr}, C_{rec}, C_{waste}$	=	concentration of substance i in the raw material, product, recycled material or waste respectively, that is processed annually (generally expressed in mg/kg for solids, mg/L for liquids)
10^6	=	conversion from milligrams to kilograms.

For organic chemicals in general, some degradation in treatment may occur so all of the chemical is not transferred to the sludge. Facilities can estimate the amount of organic compounds in the sludge by using measured data, or by subtracting the amount biodegraded from the total amount removed in treatment. The amount of removal can be determined from operating data, and the extent of biodegradation might be obtained from published studies. If the biodegradability of the chemical cannot be measured or is not known, reporting facilities should assume that all removal is due to absorption to sludge.

6.0   References

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The following Emission Estimation Technique Manuals referred to in this Manual is available at the NPI Homepage and from your local environmental protection agency (see the front of the *NPI Guide* for details):

- Emission Estimation Technique Manual for Combustion in Boilers;
- Emission Estimation Technique Manual for Surface Coating; and
- Emission Estimation Technique Manual for Fuel and Organic Liquid Storage.