

Cost-effective solvent management





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This Good Practice Guide was produced by
Envirowise

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Summary

This Good Practice Guide describes how companies that use organic solvents can save money and comply more cost-effectively with environmental legislation. Both outcomes can be achieved by improving solvent management to reduce solvent use and emissions of volatile organic compounds (VOCs).

Improved solvent management can make companies more competitive and profitable by:

- reducing the cost of buying solvents and solvent-containing materials such as inks, coatings and adhesives;
- reducing waste disposal costs;
- making it easier to comply with statutory controls on solvent use;
- improving environmental performance;
- reducing the need for pollution abatement equipment.

The Guide provides practical advice on how to implement a step-by-step approach to solvent management:

- Step 1: carry out an initial review to determine the potential cost savings and gain support for further work.
- Step 2: set up a team and give an appropriate 'champion' responsibility for investigating solvent management issues.
- Step 3: gather data to gain an understanding of solvent use and draw up a solvent mass balance.
- Step 4: analyse the collected data to identify problems and the causes of waste and unnecessary emissions.
- Step 5: consider and prioritise available improvement options in terms of costs and benefits.
- Steps 6 and 7: produce and implement an action plan with appropriate objectives, targets and actions.
- Step 8: review progress in terms of reductions in solvent use/emissions and the approach adopted.

The Guide explains how to prepare a mass balance and how to use graphical techniques to analyse solvent use and trends. A computer spreadsheet is provided on a disk in the pocket at the back of the Guide to help companies track and analyse data on solvent use.

Free advice and publications on all aspects of solvent management in different industry sectors are available from the Environment and Energy Helpline on 0800 585794 or the Envirowise website (www.envirowise.gov.uk).

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1.1 About this Guide

This Good Practice Guide is about managing the use of industrial solvents in the workplace and, in particular, reducing their use to:

- save money and thus increase profits;
- ensure compliance with environmental legislation;
- improve environmental, health and safety performance.

The Guide is aimed at companies of all sizes and in sectors that use solvents (apart from dry cleaning¹), including:

- printing;
- surface finishing;
- furniture manufacture;
- vehicle finishing;
- adhesive manufacture and use;
- coating manufacture.

The Guide is intended for those managers looking for practical ways to reduce operating costs and comply with pollution control legislation. It also goes hand-in-hand with quality management systems such as the ISO 9000 series and environmental management systems such as ISO 14001 and EMAS.

This Guide, which updates and replaces Good Practice Guide *Cost-effective solvent management (GG13)* and Good Practice Guide *Reduce costs by tracking solvents*² (GG114), contains:

- an outline of the benefits of improved solvent management;
- a brief introduction to the legislation controlling solvent use by industry in the UK;
- a description of the continual improvement solvent management process;
- a description of how to put together a solvent management plan (mass balance) in line with legislation;
- a computer spreadsheet to help you track and analyse solvent use;
- a worksheet to help you to identify cost-saving opportunities;
- industry examples illustrating the benefits of solvent management;
- information about the free publications and support available from Envirowise.

¹ See Good Practice Guide *Solvent consumption in dry-cleaning* (GG87) for practical advice on managing solvent use in this sector. GG87 is available free of charge through the Environment and Energy Helpline on freephone 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

² Both published by the then Environmental Technology Best Practice Programme in 1996 and 1998 respectively.

Use of the spreadsheet supplied on the disk in the back pocket of this Guide is not essential for successful solvent management. What is important is a systematic approach (see **section 2**) to solvent management. You can either use the computer spreadsheet described in this Guide (see **section 6**) to record and analyse your data on solvent use, or develop your own system/spreadsheet based on the methods in the Guide.

Screen printer saves with solvent recovery

Bovince Limited is a screen printer with around 48 employees. The company has a sustainability policy and a continuous improvement programme. The purchase of an automatic screen-wash unit with solvent recovery has reduced solvent use by more than 10 000 litres/year, saving around £27 000 in 1997.

Free advice and information from Envirowise

If you encounter any difficulties with the solvent management process described in this Guide or when implementing it in your company, you can contact the Environment and Energy Helpline on freephone 0800 585794 to:

- arrange to talk to a specialist Envirowise advisor;
- request a free counselling visit from an independent Envirowise advisor;
- order free publications offering practical advice specific to your sector.

1.2 Why reduce solvent emissions?

Solvents that evaporate readily at room temperature, escaping into the atmosphere, are known as volatile organic compounds (VOCs). VOCs such as acetone, methyl ethyl ketone (MEK), trichloroethylene and white spirit are widely used in industry to degrease, thin and dissolve. They are also found in many proprietary paints, inks and adhesives.

Industrial solvents and solvent-based coatings are expensive to buy at hundreds or even thousands of pounds per tonne, while waste solvents, inks and coatings are costly to dispose of because they are classified as hazardous waste. Cost-effective solvent management can therefore save - even a small site - thousands if not tens of thousands of pounds a year, often with little capital outlay. Larger users of solvent could save hundreds of thousands of pounds!

In addition, there are health, safety and environmental issues. Many organic solvents can harm human health, acting as irritants and, in some cases, as carcinogens. Some make an indirect contribution to global warming while most contribute to the formation of low-level ozone. This can cause eye, nose and throat irritation, more serious respiratory health problems, damage to crops and natural vegetation, and even damage to some rubbers and plastics. Liquid organic solvents can contaminate the ground or water supplies; 1 litre is enough to contaminate about 100 million litres of drinking water - equivalent to 50 Olympic-sized swimming pools.

Solvents have long been recognised as hazardous, and their use and disposal are subject to many legal requirements related to health, safety and environmental issues. Under the United Nations Economic Commission for Europe (UNECE) Gothenburg Protocol to the Convention on Long Range Transboundary Air Pollution (CLRTAP) 2000, the UK is required to reduce its VOC emissions by 55% of its 1990 emissions by 2010. Legislation controlling the use of solvents in the UK is outlined in **section 1.4**.

1.3 Benefits of solvent management

With coatings costing several pounds per litre and solvents hundreds - and, in some cases, thousands - of pounds per tonne, maximising material utilisation has clear benefits. Despite this, companies often waste 40% or more of their materials, particularly through excessive overspray and poor material recovery.

Productivity gains can be just as important, with the potential to increase throughput and turnover significantly without the need for extra labour or larger premises. Finally, there is the question of your company's image and reputation with its stakeholders - customers, banks, employees and local communities are now taking far more interest in environmental performance.

Did you know?

- A typical 4 m diameter storage tank can lose 500 kg/year of solvent through day-night 'breathing' losses.
- An 'average' pump seal can lose around 300 kg/year of solvent, while a typical pressurised piped system can lose as much as 2.5 tonnes/year through small leaks from pumps, flanges and valves.
- Some printing shops lose more than 25% of their solvent through fugitive (unintentional/uncaptured) emissions.

Following the advice given in this Guide can help your company become more competitive and more profitable by:

- reducing material purchase costs through reduced consumption of solvents and associated materials, eg inks, paints and adhesives;
- reducing disposal costs;
- improving overall site efficiency;
- improving product quality;
- ensuring more cost-effective compliance with environmental legislation;
- making your company more attractive to 'greener' customers and investors;
- reducing the risk of pollution incidents, which have associated clean-up costs and potential fines;
- reducing the cost of risk-based insurance premiums;
- helping to eliminate the need for abatement equipment by reducing solvent consumption to below the legislative threshold;
- helping to reduce emission concentrations/volumes so as to avoid the need for expensive abatement equipment such as thermal oxidisers;
- reducing staff absenteeism and improving staff retention due to improved working conditions;
- improving the relationships with your regulator/local authority and the local community (important in terms of reducing complaints and opposition to planning applications).

As a rule of thumb, companies can typically achieve savings worth around 1% of turnover through waste minimisation. These savings go straight to the bottom line as profit.

Motor manufacturer benefits from solvent management

A systematic, computer-based approach to solvent management has allowed a major UK motor manufacturer to identify opportunities to minimise waste, lower VOC emissions and reduce investment in abatement equipment at one of its sites. A computer spreadsheet developed by the company is used to track solvent use in the paint shop and perform mass balance calculations.

By 1997, improvements identified as a result of using the solvent management system had resulted in cost savings of £60 000/year through lower expenditure on chemicals, solvents and waste disposal. A fall in VOC emissions of nearly 40% allowed the company to defer major investment in abatement equipment. The mass balance analysis is also used to demonstrate compliance with pollution control legislation.

In 2001, as a result of the continuous improvement approach, the company achieved a further 50% reduction in VOC emissions.

For more information see *Continuing to profit from computer-based solvent management* (CS409).

1.4 Solvent control legislation

Although vehicle use leads to significant VOC emissions, the majority of VOC emissions in the UK come from industry and the domestic use of paints. In terms of industrial emissions, the UK must comply with the EC Solvent Emissions Directive (SED) 1999 and thus has strict regulations governing the use of organic solvents and solvent-containing materials by industry. The application of good solvent management is integral to the way these regulations work so following the advice in this Guide should help you comply with legal requirements.

1.4.1 VOC pollution prevention and control legislation

Most companies that consume more than 5 tonnes/year of organic solvents (1 tonne/year for vehicle refinishers) or 20 tonnes/year of coating are regulated under the Local Air Pollution Control (LAPC) regime (Part B processes). LAPC was introduced under Part I of the Environmental Protection Act 1990 and will gradually be replaced under the Pollution Prevention and Control Act 1999 by Local Air Pollution Prevention and Control (LAPPC). LAPPC represents a continuation of LAPC, but with some modifications to take account of the requirements of the EC Integrated Pollution Prevention and Control (IPPC) Directive³.

Under the Pollution Prevention and Control (PPC) regime, most companies consuming more than 150 kg/hour or 200 tonnes/year of solvent will be deemed Part A2 processes and will be regulated under Local Authority Integrated Pollution Prevention and Control (LA-IPPC). Consumption is defined as the total input of organic solvents into an installation in a 12-month period, excluding any VOCs recovered for re-use.

Local authorities are responsible for enforcing both Part B and Part A2 processes, while larger and more polluting Part A1 processes are regulated by the Environment Agency in England and Wales, the Scottish Environment Protection Agency (SEPA) in Scotland and the Environment and Heritage Service (EHSNI) in Northern Ireland⁴.

³ Companies regulated under LAPC will switch to the new LAPPC regime in the year commencing 1 April 2004.

⁴ For more information about relevant regulations visit the NetRegs website (www.environment-agency.gov.uk/netregs/), developed by the Environment Agency in collaboration with SEPA and EHSNI.

Detailed requirements are set out in the latest versions of the appropriate Process Guidance Notes⁵, which also take account of the requirements of the SED. The most relevant for the purposes of this Guide are the PG6 series of notes covering coating operations and printing⁶, such as:

- PG6/20 *Paint application in vehicle manufacturing*;
- PG6/23A *Coating of metal and plastic*;
- PG6/23B *Surface cleaning*;
- PG6/32 *Adhesive coating processes*;
- PG6/34 *Respraying of road vehicles*.

In the Process Guidance Notes, VOC emission limits are expressed as a concentration in terms of abated emissions (typically 50 mg/m³ as carbon) and/or as total mass emissions per unit of production. For example, the limit stated in PG6/20 (vehicle manufacturing) for existing processes is 60 g of emitted VOC per m² of coated surface⁷. In addition, LAPPC introduces limits for fugitive emissions.

1.4.2 Ways of achieving compliance

Under most Process Guidance Notes, compliance can be achieved through abatement or through a Solvent Reduction Scheme, which aims for a 'target emission' using a Solvent Management Plan (SMP) mass balance approach such as that described in this Guide. This approach involves constructing inventories of materials consumed and disposed of, and may involve the identification of individual solvents or solids. The definitions (see **section 3.1.4**) provided in the relevant Process Guidance Note provide a framework for the mass balance calculation and must be used in all calculations relating to the SMP.

The SMP is used to determine:

- annual solvent consumption (all processes and activities);
- fugitive emissions (for installations covered by SED);
- actual annual emissions (for installations using the Solvent Reduction Scheme).

These data must be submitted to the regulator each year in the form of a mass balance.

For free advice on the latest situation affecting your company, contact the Environment and Energy Helpline on 0800 585794, which can put you in touch with a specialist in your sector.

1.5 Other relevant legislation

Duty of Care requirements for controlled waste, established by Part II of the Environmental Protection Act 1990, place producers and holders of waste under a responsibility to ensure that it is dealt with in a safe and appropriate manner. Controlled waste must only be transferred to licensed organisations and written documentation must be completed and kept. Waste transfer

⁵ Information about Process Guidance Notes, and consultation on new or updated Process Guidance Notes are given on the Defra website (www.defra.gov.uk/environment/) and the Environment Agency website (www.environment-agency.gov.uk).

⁶ Available from TSO (The Stationery Office) (Tel: 0870 600 5522; website: www.tso.co.uk and e-mail: customer.services@tso.co.uk).

⁷ To be reached by October 2007. New processes or activities must achieve this limit immediately.

notes (using six-digit European Waste Catalogue Codes) have to be completed for non-hazardous waste and consignment notes for special/hazardous waste⁸. Most industrial solvents and solvent-based materials are classified as special/hazardous waste when no longer required for site processes. For more information about waste and other relevant regulations, contact the Environment and Energy Helpline on 0800 585794.

Environmental legislation may vary between different parts of the UK. For further information on relevant legislation and new legislative developments affecting your company:

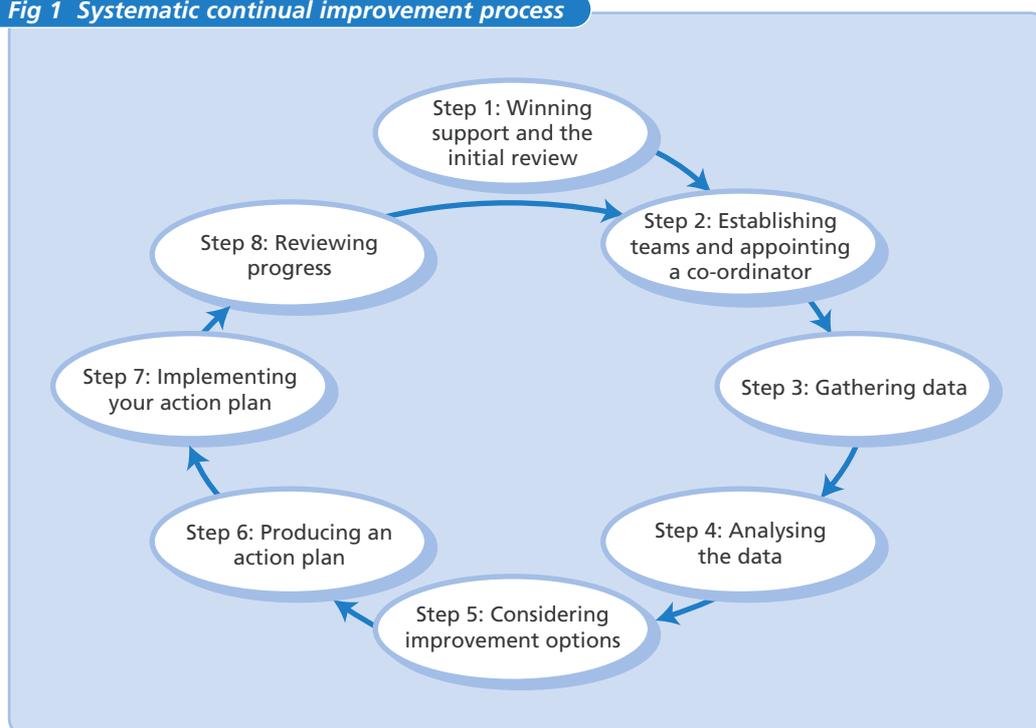
- contact the **Environment and Energy Helpline on 0800 585794**;
- contact the appropriate environmental regulator;
- visit the NetRegs website (www.environment-agency.gov.uk/netregs/) developed by the Environment Agency in collaboration with SEPA and EHSNI.

This Guide does not aim to cover health and safety issues. Further advice and guidance are available from the Health and Safety Executive Info Line on 0541 545500.

⁸ Hazardous waste is regulated currently under the Special Waste Regulations. The Hazardous Waste Regulations are expected to supersede the Special Waste Regulations soon.

The best way to improve your solvent management and reduce costs is to take a systematic continual improvement approach such as that set out in Fig 1. This approach offers a logical step-by-step process that allows progress to be made at a pace that suits you. The eight steps are described below.

Fig 1 Systematic continual improvement process



2.1 Step 1: Winning support and the initial review

2.1.1 Making the business case

Nothing will happen without senior management commitment. You will therefore need to set out a clear business case for measuring performance efficiency. The key points to stress are that measuring and improving performance can:

- save the company money by reducing material/utility consumption and waste generation;
- help to ensure and demonstrate compliance with environmental legislation;
- improve the management of materials and waste, thereby reducing potential environmental risks from spills and leaks and associated prosecution/liability issues.

It is also worth highlighting any past savings by the company or savings made by other companies. This Guide and other Envirowise publications contain many examples of companies that have benefited from improving their solvent management.

Vehicle refinisher reduces both costs and VOC emissions

The paintshop within a car dealership and vehicle refinisher has six operators. Improved working practices, good housekeeping and the introduction of high volume low pressure (HVLV) spray guns allowed the company to save approximately £10 000/year while reducing VOC emissions from 2.5 tonnes/year to less than 1 tonne/year.

2.1.2 Carrying out an initial review

An initial review can help in gathering the basic information you need to gain support from senior management. It is important to highlight opportunities for quick savings and a short payback on any investments.

Completing an initial review involves:

- Using existing data on resource use and disposal, eg data from existing meters, purchase and sales records, and waste disposal invoices.
- Walking round the site:
 - talking to key people;
 - identifying areas of waste/potential improvement, eg using Good Practice Guide *Reducing solvent use by good housekeeping* (GG413) as a checklist.
- Estimating the approximate savings associated with a few of the more promising measures identified. The appendix contains an example worksheet to help you to demonstrate potential cost savings and payback. Fig 2 shows a worked example of this worksheet from a fictitious company.

The initial review should also help you to start identifying gaps in data and how to address them.

Free help from Envirowise

If you employ fewer than 250 people at your site, you could benefit from a *FastTrack* visit. This is a confidential, on-site waste review carried out by an environmental advisor, which will effectively complete the initial review for you. The visit includes up to a day's free advice. For more information or to request a *FastTrack* visit, phone the Environment and Energy Helpline on 0800 585794 or visit the Envirowise website (www.envirowise.gov.uk).

Fig 2 Example initial review worksheet

Area/department: Process 3									
Potential cost-saving/ waste reduction measure	Quantity affected A	Unit cost B	Annual cost C	Potential saving D	Potential annual savings $E = (C \times D)/100$	Approximate capital cost F	Payback period $(F/E) \times 12$		
Coating delivery in intermediate bulk containers (IBCs) rather than drums (less residue waste)	20 tonnes	£6 000/tonne	£120 000	5%	£6 000	£0	Immediate		
Planned maintenance (less solvent leakage)	25 tonnes	£900/tonne	£22 500	10%	£2 250	£500 (software)	3 months		
Electrostatic spraying (less paint overspray)	40 tonnes	£3 000/tonne	£120 000	10%	£12 000	£4 000 (spray guns)	4 months		
Solvent recovery (reduced disposal/cleaning solvent costs)	40 tonnes	£300/tonne	£12 000	90%	£10 800	£20 000 (still)	22 months		
Total					£31 050	£24 500	9 months		

2.2 Step 2: Establishing teams and appointing a co-ordinator

2.2.1 Establishing solvent management teams

In small companies with only a few employees, it is usually the manager plus one or two staff who have to take on responsibility for solvent management.

In larger companies, responsibilities/knowledge/skills can be spread across functions/departments. In such cases, it is desirable (if not essential) to establish a team that includes:

- environmental, health and safety managers;
- manufacturing and product development managers;
- shop-floor staff.

For most team members the role will be part-time, but they should be identified at the start and called upon as necessary. Additional people can be brought in as required, eg procurement staff may need to be involved if a new material is being considered. In some cases, it may be necessary to establish more than one team, eg where there is more than one site or division. Where process/product changes are proposed, it is also often necessary to involve suppliers to help with technical problems, and customers to ensure that their concerns can be resolved.

2.2.2 Appointing a co-ordinator

Any improvement team needs an empowered and enthusiastic co-ordinator or 'champion' to lead and facilitate the work. The co-ordinator should preferably be someone with:

- sufficient authority to make things happen or direct access to someone with that authority;
- a good understanding of how the company operates in all areas and, preferably, personal contacts in these areas;
- an ability to listen to the views of others and make objective decisions;
- enthusiasm and a belief in waste minimisation and its commercial benefits.

Co-ordinators are likely to have to fit in environmental responsibilities alongside existing ones and it is important that time is set aside for this role. For more information, see Good Practice Guide *Saving money through waste minimisation: teams and champions* (GG27)⁹.

2.3 Step 3: Gathering data - monitoring material use and waste

Understanding coatings/solvent use and losses through emissions is essential to ensure compliance with environmental legislation and to allow targeted and cost-effective improvements.

Solvent management is about accurate measurement of inputs to, and outputs from a process in order to estimate VOC emissions and track use. The data are analysed by producing what is known as a mass balance. In simple terms, this means that what goes in (in weight terms) must come out. In other words:

Emissions = Inputs – Outputs

⁹ Available free of charge through the Environment and Energy Helpline on freephone 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

Some of these emissions are captured and vented through a stack(s) (to be abated or otherwise), while others are fugitive or uncaptured and are lost primarily through leaks and spills.

The preparation and use of mass balances are described in more detail in **section 3**, which also gives guidance on useful data sources, data gathering and estimation.

2.4 Step 4: Analysing data and investigating potential problems

Solvent/material use and emissions should be analysed with the aim of:

- Meeting statutory requirements.
- Identifying areas of potential waste so as to improve efficiency and save money. The best way of achieving this is by using graphs (see **section 4**).

At this stage, brainstorming sessions can be useful in identifying potential causes of inefficiencies/problems. Make sure you involve all relevant staff in these investigations, including shop-floor staff who are often in the best position to help with constructive comments and suggestions.

2.5 Step 5: Considering improvement options

Once the causes of the various problems have been investigated, it is worth considering the costs, benefits and feasibility/difficulty of doing something about them. In terms of costs, you need to consider:

- material costs (solvent and solvent-based materials);
- disposal costs;
- energy costs;
- productivity costs (ie lost production).

These costs will give some indication of the benefits of making the change and will allow the payback period to be calculated.

These data, along with some brainstorming, can then be used to set priorities and to persuade senior managers to implement the necessary improvements.

Staff suggestion schemes, linked to some sort of reward, can also be useful in terms of generating improvement ideas. Don't be put off by those who tell you: "That's the way we've always done it" or "We tried that and it didn't work". Technology and costs change, so what was not possible or economic a few years ago may well be now.

Put easier and low-cost measures at the top of the list of priorities so that results can be achieved quickly. This will motivate everyone concerned and give them confidence to tackle the more difficult and more expensive measures later. In some cases, it may be necessary to carry out trials to ensure that suggested changes are feasible.

2.6 Step 6: Producing an action plan

Having considered the various options, prepare an action plan. This should set out:

- the various problem areas;

- the proposed priority improvement measures (complete with cost benefit information);
- ambitious but achievable targets and timescales.

To assess progress, targets need to relate to parameters that are being measured. A typical target could be, for example, to reduce overall solvent use per unit of production (eg tonne) by 20%.

Consult as many relevant staff as possible to obtain their comments on the practicality of the plan and any potential barriers. It is also important to make everyone aware of the potential benefits of the measures (improved profitability, better job security, etc). This can be achieved through presentations, newsletters and posters on notice-boards. It is also worth considering incentive schemes.

The final plan should be agreed at a senior management level to gain their full commitment.

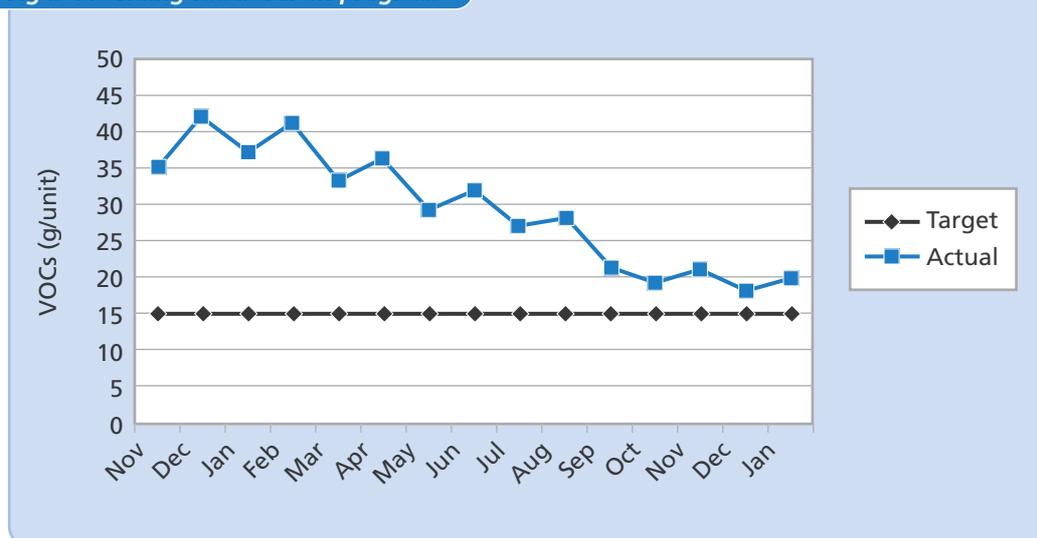
2.7 Step 7: Implementing your action plan

Implementing your action plan involves detailed teamwork, but this should be made easier and more productive because of the steps that have gone before it. In some cases, you will need to prepare detailed implementation plans for specific improvement projects within the overall action plan.

It is again important to:

- Get everyone involved in the implementation of the plan.
- Keep people informed of progress (through notice-boards, newsletters, team briefings and intranet systems) so as to maintain interest and motivation. It is often best to use graphs to provide this feedback in a clear visual format (see Fig 3).

Fig 3 Providing feedback on progress



2.8 Step 8: Reviewing progress

Once the plan is being implemented, you should review progress against targets regularly - perhaps at first every six months and then every year. It may also be helpful to review:

- How successful process monitoring and data gathering have been.
- How successful the team itself has been. The team and the co-ordinator may need to change as the work progresses.

Remember that this is a continual improvement process, and that improvements take time and circumstances change. However, significant improvements and savings help to gain support for further work.

Solvent reduction programme reduces operating costs at truck cab manufacturer

ABT Products Ltd employs 70 people in the manufacture of truck cabs. Use of an autophoretic coating plant has reduced paint use by 8 tonnes/year and resulted in savings of £35 000/year. A switch to a water-based paint has eliminated VOC emissions and reduced waste disposal costs by £3 000/year. An additional benefit is that the site is now well under the 5 tonne compliance threshold for Local Air Pollution Control (LAPC).

Data gathering and estimation

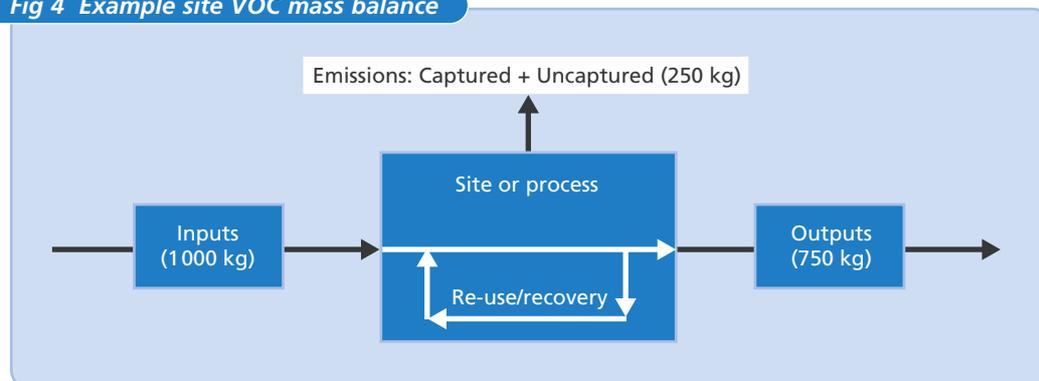
This section outlines the ways of collating basic solvent use data for subsequent analysis. An understanding of the efficiency of your solvent use and emissions is essential for targeted and cost-effective improvements. It may also be necessary to enable you to demonstrate legal compliance.

Remember: if you don't measure it, you can't manage it.

3.1 Mass balance calculations

Section 2.3 introduced the concept of mass balance as the key mechanism by which you can estimate VOC emissions and track solvent use. In simple terms, this means that what goes in (in weight terms) must come out (as shown in Fig 4).

Fig 4 Example site VOC mass balance



The **Inputs** in the mass balance are the coatings and solvents that you buy in and the **Outputs** are the various waste streams and/or solvent-based products. The difference between the two is the solvent **Emissions**; this includes both captured and fugitive emissions.

The best approach is to first calculate the mass balance of the overall site process to obtain an overview of solvent use and waste. Sub-processes within the overall operation can then be examined, one by one, to identify the main areas of inefficiency or waste generation.

3.1.1 Why is mass used?

How much solvent/VOCs in the materials that you use and the wastes that you generate is determined in terms of mass (ie weight) because:

- it is the VOCs, rather than the air or liquid they are mixed with, that do the damage;
- regulatory limits are presented in mass terms;
- matter (mass) is always conserved and hence the total mass of substance remains the same - this gives a 'known' that can be used to calculate 'unknowns' in a mass balance;
- volumes change with variations in temperature and pressure;
- every material has a different mass of molecules for a given volume, ie densities (eg grammes per litre) vary from one material to another;

- coatings, inks, etc contain only a certain proportion of solvent (the rest is solids/pigment and other ingredients);
- converting everything into mass of solvent allows addition, subtraction and multiplication even though the mass balance involves materials of different densities and solvent content.

3.1.2 Converting volume to mass

Paints, inks and adhesives vary enormously in terms of their solvent content, which is typically 250 - 900 grammes of solvent per litre¹⁰. Even pure solvents vary significantly in their density (see Table 1).

The solvent content of a particular material should be given on its packaging or in the safety/technical data sheet for the product.

Table 1 Density of some common industrial solvents

Solvent	Density (g/litre)
White spirit	775
Methanol	791
Ethanol	789
Isopropyl alcohol (propan-2-ol)	786
Acetone (propan-2-one)	791
Methyl ethyl ketone	805
Toluene	867
Xylene	881
Trichloroethylene (1,1,2-trichloroethene)	1 460

3.1.3 Solvent content of thinned coatings

Care is needed with thinned coatings as their solvent content will be different from the values given in the data sheets for the 'original' material as supplied. The example below shows how to calculate the solvent content of thinned materials such as coatings.

Worked example

A coating is 60% solvent by weight and has a density of 900 g/litre.

Solvent content of coating = $900 \times 60/100 = 540$ g/litre

During thinning, 0.3 litres of solvent with a density of 800 g/litre is added to every litre of original coating (ie 3 parts to every 10 parts).

The solvent content of the diluted coating is calculated as follows:

Mass of solvent in the 0.3 litres added to each litre of coating	= $0.3 \times 800 = 240$ g
Mass of solvent already in 1 litre of coating	= 540 g
Total solvent content in diluted coating	= $240 + 540 = 780$ g
Total volume of thinned coating	= 1.3 litres
Solvent content of thinned coating	= $780/1.3 = 600$ g/litre

¹⁰ There are 1 000 g in a kg (1 000 kg in a tonne), so 900 g/litre is equivalent to 0.9 kg/litre.

3.1.4 Definitions used in mass balance calculations

The definitions used in mass balance calculations in this Guide are given in Table 2. Those for inputs and outputs are as given in LAPPC/LAPC Process Guidance Notes for the compilation of a Solvent Management Plan (SMP) (see **section 1.4.2**).

Captured emissions are those that are removed by extraction systems and discharged to the atmosphere (with or without abatement) via ducts to stacks or vents. General extraction of the workplace via vents and windows, air-conditioning, etc is considered part of uncaptured fugitive emissions.

Table 2 Definitions used in mass balance calculations

Symbol	Definition
Inputs	
I	Inputs of organic solvent in the timeframe over which the mass balance is being calculated.
I1	The quantity of organic solvents or their quantity in purchased preparations, which are used as input to the process/activity (including cleaning solvents).
I2	The quantity of organic solvents or their quantity in preparations recovered and re-used as solvent input to the process/activity. Recycled solvent is counted every time it is used to carry out the activity.
Outputs	
O	Outputs of organic solvent in the timeframe over which the mass balance is being calculated.
O1	Emissions in captured waste gases.
O2	Organic solvents lost in water; if appropriate, taking into account wastewater treatment when calculating O5.
O3	The quantity of organic solvents which remain as contamination or residue in products output from the process/activity.
O4	Uncaptured (fugitive) emissions of organic solvents to air. This includes the general ventilation of rooms, where air is released to the outside environment via windows, doors, vents and similar openings.
O5	Organic solvents and/or organic compounds lost due to chemical or physical reactions including, for example, those which are destroyed (eg by oxidation or other waste gas or wastewater treatments) or captured (eg by adsorption), as long as they are not counted under O6, O7 or O8.
O6	Organic solvents contained in collected waste.
O7	Organic solvents or organic solvents contained in preparations which are sold or are intended to be sold as a commercially valuable product.
O8	Organic solvents contained in preparations 'recovered' for re-use, but not as input into the process/activity (as long as not counted under O7).
O9	Organic solvents released in other ways.
Stock	
IS	Initial stock.
PS	Purchased stock.
FS	Final stock during accounting period.
DS	Stock disposals/sales.
Emissions	
E	Total emissions to air.
EC	Captured (non-fugitive) emissions to air.
F	Fugitive (uncaptured) emissions to air.

3.1.5 How to perform a mass balance calculation

Before you start a mass balance calculation to determine your solvent emissions, you need a clear idea of your inputs and outputs. It is also necessary to consider stock changes. Some of these values will be known, some can be measured and some can be estimated. **Section 3.2** gives information on possible sources of these data.

■ **Inputs** are generally just the solvents purchased (or obtained at no cost) and used as input to the process/activity (I1). I1 includes coatings, dilutants and cleaning solvents. Solvents in preparations recovered on-site and re-used as solvent input to the process/activity (I2) are usually ring-fenced (see **section 3.1.6**) and if so, may be excluded from the emissions calculation.

■ **Stock changes:** $I1 = \text{Initial stock} + \text{Purchased stock} - \text{Final stock}$ (ie $IS + PS - FS$).

In other words, some purchases just go to increase stocks, ie material that is not actually used in the process during the accounting period (eg in the month in question).

■ **Outputs** include solvents appearing in any one of a range of outputs from a process/activity:

- in captured waste gases (O1);
- lost in water (O2);
- contamination or residue in products (O3);
- uncaptured emissions to air (O4);
- loss due to chemical or physical reaction (O5);
- solvents in collected/stored waste (O6);
- solvents in commercial product (O7);
- solvents released in other ways, eg sent off-site for disposal (O9).

■ Solvent that is sent for recycling/re-use off-site is also counted as an output (O8). Solvents sent for recovery/re-use on-site are generally within the ring-fence and if so, may be excluded (they could otherwise be designated O10).

■ When considering product and waste outputs (O6, O7 and O8), it is necessary to take stored material awaiting delivery/collection (ie stock) into account. The opposite to inputs applies, ie product/waste may have been produced but not taken off-site in the accounting period.

Product and waste outputs = Final stock + Stock disposals/sales – Initial stock

ie $(O6 + O7 + O8) = FS + DS - IS$.

■ **Emissions to air** consist of captured waste gases and fugitive emissions (O1 + O4).

■ Total emissions to air (E) = $O1 + O4 = I1 - O2 - O3 - O5 - O6 - O7 - O8 - O9$.

■ Captured (non-fugitive) emissions to air (EC) = $O1 = I1 - O5 - O6 - O8$.

■ Small errors in input and certain output values will give a large error in emissions.

Example mass balance

In this simplified example, the accounting period used for the mass balance is a year. O2, O3, O5 and O7 are negligible.

At the start of the year, a company has in stock 500 litres of solvent for thinning/cleaning and 1 000 litres of coating. The solvent has a density of 800 g/litre (0.8 kg/litre) and the coating contains 350 g/litre (0.35 kg/litre) of solvent.

During the year, it purchases 6 000 litres of solvent and 10 000 litres of coating.

At the end of the year, it has 700 litres of solvent in stock and 800 litres of coating.

At the start of the year, there were 40 litres of spent solvent and 200 litres of waste coating.

During the year, the company disposes of 1 000 litres of spent solvent and 2 000 litres of made-up coating, which had been diluted 20% (by volume) with solvent to give a mixture containing 425 g/litre (0.425 kg/litre) of solvent.

At the end of the year, the company has 80 litres of spent solvent and 160 litres of waste coating.

Overall input to the process: = Initial stock + Purchased stock – Final stock

$$= [(500 \times 0.8) + (1\,000 \times 0.35)] + [(6\,000 \times 0.8) + (10\,000 \times 0.35)] - [(700 \times 0.8) + (800 \times 0.35)]$$

$$= 750 + 8\,300 - 840 = 8\,210 \text{ kg}$$

Waste-based outputs from the process:

= Solvent in stored waste at end of year + Solvent in disposed of waste – Solvent in stored waste at beginning of year

$$= [(80 \times 0.8) + (160 \times 0.425)] + [(1\,000 \times 0.8) + (2\,000 \times 0.425)] - [(40 \times 0.8) + (200 \times 0.425)]$$

$$= 132 + 1\,650 - 117 = 1\,665 \text{ kg}$$

Overall emissions to air: = 8 210 – 1 665 = 6 545 kg, ie 80% of the inputs are emitted to air.

3.1.6 Ring fencing

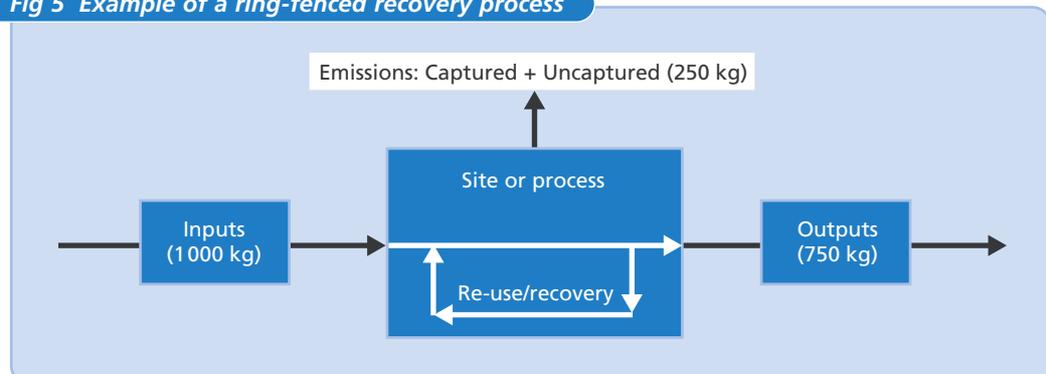
Ring fencing involves drawing a 'box' around a process or processes. For the purposes of the mass balance calculation, anything can go on within the box (eg re-use and recovery). You don't need to know about what goes on inside the box - only what goes in and out of the box is important.

It is easiest to think of the ring fence being around the shop floor or process part of the site. The material store and the product and waste storage areas should be kept outside the ring fence. The process shown in Fig 5 is a ring-fenced process (NB Fig 5 is a repeat of Fig 4).

The material stock, the waste 'stock' and the product stock are 'outside' the ring-fenced area; otherwise, you would have no knowledge of them and would not be able to take them into account when calculating the 'real' inputs, outputs and emissions relating to the site processes. Emissions from the material storage areas (eg evaporation from bulk tanks) are recorded as stock differences (between the beginning and end of the accounting period) and hence as process inputs. They are thus not omitted, but are taken into account as part of the overall emissions figure.

A build-up of stock, waste and product 'inside' the ring-fenced area (eg material kept on the shop floor and not recorded) will lead to errors in the consumption figure because, from outside the 'box', it will appear that inputs are up or outputs are down.

Fig 5 Example of a ring-fenced recovery process



When processes such as distillation are not ring-fenced, they have to be treated separately and then added to the emissions. This makes the calculation more complicated, as illustrated by the example below.

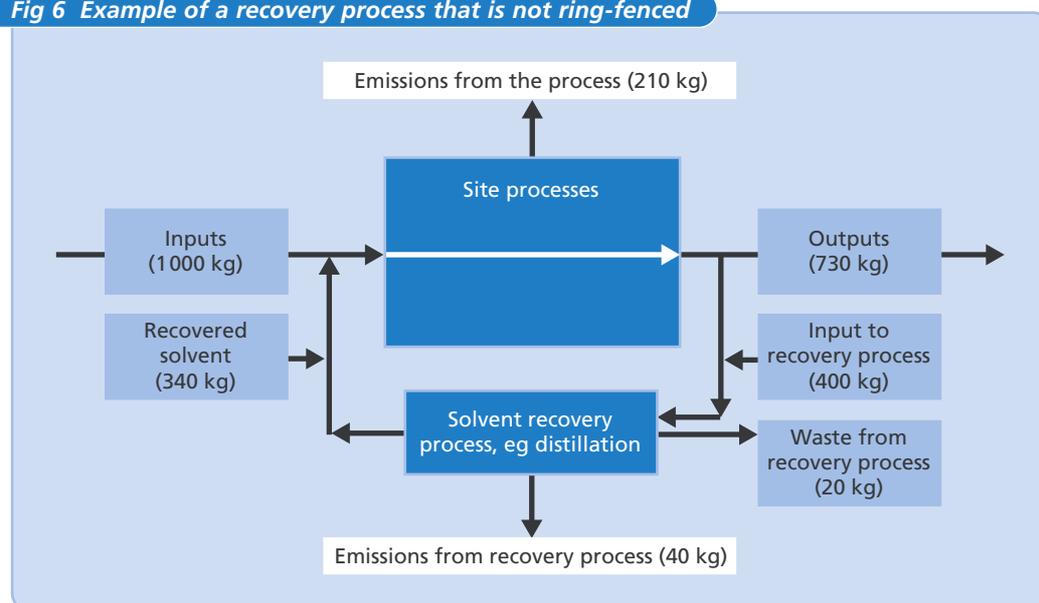
Example mass balance calculation for a process that is not ring-fenced

For the process shown in Fig 6, the inputs to the main site/process amount to 1 340 kg (1 000 + 340 kg) and the outputs from it amount to 1 130 kg (730 + 400 kg), giving emissions of 210 kg.

The input to the recovery process (eg distillation) is 400 kg and the outputs amount to 360 kg (340 kg of recovered solvent plus 20 kg of solvent in the sludge from the recovery unit). This gives emissions to air from the recovery process of 40 kg.

As in the ring-fenced example shown in Fig 5, the total emissions from the example shown in Fig 6 are 250 kg (210 kg + 40 kg).

Fig 6 Example of a recovery process that is not ring-fenced



3.1.7 Estimating fugitive emissions

In terms of LAPC/LAPPC Process Guidance Notes for Solvent Management Plan calculations and Solvent Emissions Directive definitions, fugitive emissions are those that are:

- lost in water (O2);
- left as contamination or residue in products (O3);
- uncaptured emissions to air (O4);
- solvent released in other ways (O9).

Therefore, fugitive emissions (F) = O2 + O3 + O4 + O9 = I1 – O1 – O5 – O6 – O7 – O8.

Fugitive emissions can therefore be estimated from the individual outputs, and calculated by addition or subtraction.

Fugitive emissions to air (O4) can be determined if you have calculated the total emissions to air (E) and know the value for captured emissions (O1), ie O4 = E – O1.

O1 can be calculated by working out the captured mass emissions, eg directly to air or to abatement systems. Mass emissions are equivalent to the solvent concentration upstream of any abatement equipment (ie as it leaves the process rather than after it has been abated) multiplied by the flow rate of the solvent-laden air stream. An example of this approach is given below. For further information, see *Monitoring VOC emissions: choosing the best option* (GG203)¹¹.

Worked example: estimating fugitive emissions from mass balance data

Monitoring of three stacks (without abatement) for captured emissions indicates that average VOC concentrations are: 250 mg/Nm³, 100 mg/Nm³ and 50 mg/Nm³ and the respective average airflows are 2 000 Nm³/hour, 1 500 Nm³/hour and 3 000 Nm³/hour. The working year totals 4 000 hours.

$$\begin{aligned} \text{Captured emissions (EC)} &= \frac{[(250 \times 2\,000) + (100 \times 1\,500) + (50 \times 3\,000)] \times 4\,000}{1\,000\,000} \\ &= 3\,200 \text{ kg} \end{aligned}$$

Assuming that total emissions (E) is 6 545 kg as in the example in section **3.1.5**:

$$\text{Fugitive emissions (O4)} = 6\,545 - 3\,200 = 3\,345 \text{ kg, ie slightly over 50\% of total emissions.}$$

Using emission factors

Calculation of fugitive emissions using mass balance results only gives meaningful results if E and O1 can be measured accurately. This is often not possible and fugitive emissions then need to be estimated using factors (preferably those derived from fugitive monitoring work).

Emission factors work by giving a rate of leakage for various sources (eg leaking pipework) from which an overall fugitive figure can be calculated. Emission factors can also be derived for a particular operation, eg for mixing a typical batch of ink or paint.

It is first necessary to identify potential sources and then derive emission factors for each source. For example, potential sources of fugitive emissions in printing include:

- press room general ventilation;
- cleaning department general ventilation;
- ink mixing department general ventilation;
- vapour losses from tanks, piped systems, spillages, etc.

The US Environmental Protection Agency's *Protocol for equipment leak emission estimates* (EPA 453/R-95-017)¹² provides some values. However, it is more accurate to derive particular emission factors through monitoring. Fugitive monitoring generally involves measuring the VOC concentration and gaining an indication of flow rate, eg the ventilation extraction rate from the mixing kitchen.

Some factors may relate to a system and apply when the system is in use/pressurised, and some may apply to a particular operation.

Table 3 overleaf shows the extent of fugitive losses from piped solvent distribution systems. The associated cost of this loss can be significant.

¹¹ Available free of charge through the Environment and Energy Helpline on freephone 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

¹² For more details, see the US EPA website (www.epa.gov/ttn/chief/efdocs/lks95_ch.pdf).

Table 3 Typical solvent losses from piped solvent distribution systems

Equipment	Carrying	Number of sources		Emissions factor (kg/hour/source)	Total emissions (kg/hour)
Valves	Light liquid	10	Leaking	0.0852	0.85
		90	Non-leaking	0.00171	0.15
Pump seals	Light liquid	2	Leaking	0.437	0.87
		13	Non-leaking	0.012	0.16
Flanges	All	10	Leaking	0.0375	0.38
		250	Non-leaking	0.00006	0.02
Pressure relief devices	Gas/vapour	1	Leaking	1.691	1.69
		9	Non-leaking	0.0447	0.40
Total					4.52
Annual total (24-hour, 365 day working)					39.6 tonnes
Annual cost (@ £900/tonne)					£35 640

Worked example: using emission factors

Fugitive monitoring reveals that the site has one leaking pump seal, two leaking valves and five leaking flanges. The working year totals 4 000 hours. Mixing takes places every 8 hours of operation.

From Table 3, the emission factors (in kg/hour/source) are:

Leaking pump seal	= 0.437
Leaking valve	= 0.0852
Leaking flange	= 0.0375
Mixing operation	= 0.12 per mix
Fugitive emissions	= [(1 × 0.437) + (2 × 0.0852) + (5 × 0.0375) + 0.12/8] × 4 000
	= 3 240 kg

More significant fugitive emissions should be measured as accurately as possible; less significant fugitive emissions are less important in the overall estimate.

3.2 Data sources for mass balance calculations

3.2.1 Site-level inventory

At the site-wide level, information on the quantity and solvent content (by weight) of inputs and outputs for the mass balance can generally be obtained from a number of readily available sources (see Table 4 overleaf). Fig 7 (overleaf) gives an example of solvent flow through a small manufacturing site.

Fig 7 Example solvent flow through a small manufacturing site

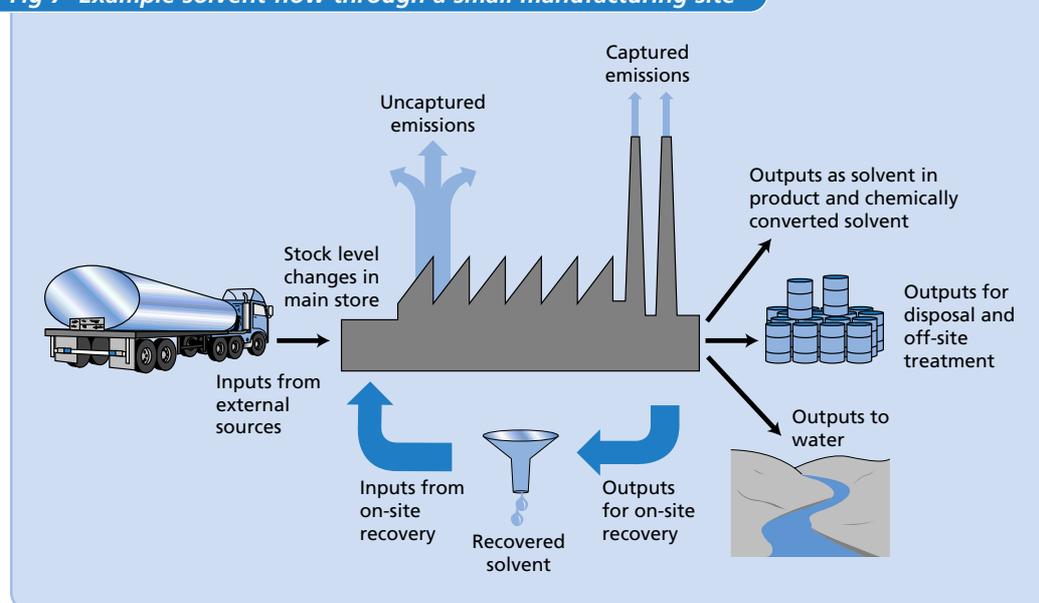


Table 4 Useful data sources

Data requirement	Source of information
Inputs	
Bought-in solvents	Purchase/dispense records, stocktaking, materials database
Bought-in coatings	Purchase/dispense records, data sheets, stocktaking, materials database
Outputs	
Solvent in product	Sales records, analyses
Waste* solvents (eg from cleaning)	Disposal/sales records, audits, analyses, spillage logs
Waste* coatings (process residues)	Disposal/sales records, audits, analyses, spillage logs
Solvent recovery sludges	Disposal records, audits, analyses
Solvent lost in water (discharge to drain under consent)	Trials, analyses, estimates
Waste gas emissions	Monitoring, analyses
Loss to chemical/physical reactions (abatement)	Needs to be calculated, measured, or details may be available from supplier

* Waste means all residue materials including those sent off-site for re-use/recovery.

Most solvent-based coatings have a solvent content of 250 - 750 g/litre and many companies have a spreadsheet or database that allows the solvent content of their materials to be recorded. Care is necessary when coatings are thinned using solvents (see **section 3.1.3**).

As this stage, you are considering site-level inputs and outputs to the process (as used) and not to the site as a whole. It is therefore important to be aware of material stock and waste that are sitting in the yard but are possibly not relevant to the calculation period.

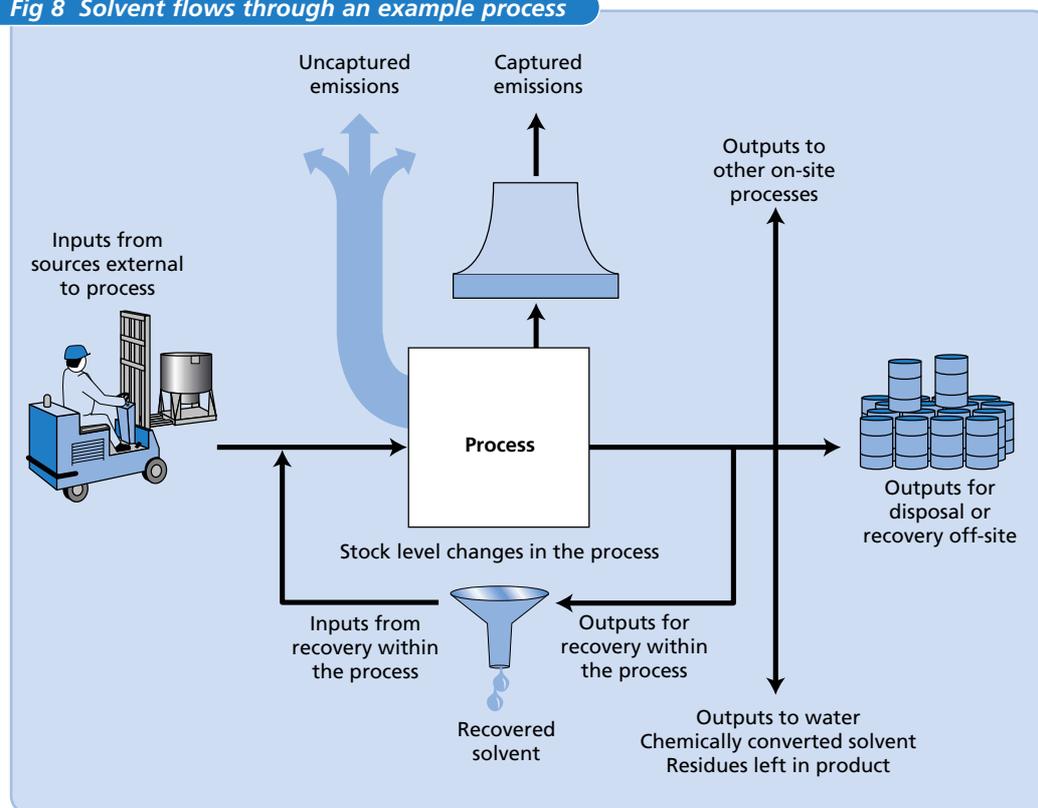
As explained in **section 3.1.6**, solvent recovery on-site can be ignored (if ring-fenced) in terms of waste in and recovered solvent out. However, any sludges from the recovery process are part of the waste outputs from the site.

When recording data for analysis, it is important to stick to regular intervals of time. It is best to record data on a four-weekly basis (if possible), with annual summaries covering 13 periods. Using calendar months introduces a systematic variation in the time period and thus makes period-to-period comparison more difficult.

3.2.2 More detailed data gathering

Having established a site-level picture, the next stage is to break down your manufacturing process into its separate component processes, each with its inputs, outputs and emissions. The principle is the same as for the site as a whole and will help you to identify possible sources of solvent loss and VOC emissions, eg by comparing similar processes. Fig 8 shows an example of solvent flows through an individual process.

Fig 8 Solvent flows through an example process



To complete your calculations for specific processes or parts of a process, it may be necessary to undertake specific data gathering exercises.

When tracking solvents through individual processes, use meters (where materials are piped) or a dispense log (see Fig 9 overleaf). Ideally, you should record everything that goes into and comes out of each key process.

A log such as the one shown in Fig 9 can make staff more accountable and hence more careful with materials. Don't forget to stick to regular time intervals for all data gathering.

Fig 9 Example solvent dispense log

Origin:	Main ink mixer		Destination:	Press No. 1	
Date	Time	Material	Quantity (litres)	Operator	Signature
1/10/03	8:30	Black ink	20 litres	P. Smith	P. Smith
	10:30	Cleaner A	2 litres	E. Jones	E. Jones
	14:30	Green ink	15 litres	P. Smith	P. Smith
	16:30	Cleaner B	5 litres	J. Brown	J. Brown

3.2.3 Solvent measurement: hints and tips

Solvents can be measured in many ways. Some hints and tips are given below.

- Fit tanks with level meters or load cells to keep track of bulk stocks.
- Fit piped systems with flow meters/data loggers to track flows to particular parts of the site/process.
- Weigh small part-filled containers such as 5-litre cans (remember to subtract the weight of the empty can).
- Use dipsticks for large containers. Make sure that the dipstick is straight, calibrated properly and placed vertically into the container.
- Mark transparent containers such as IBCs to indicate fixed (eg 10-litre) intervals.
- Decant from large containers such as drums using set measures such as litre jugs (wear appropriate gloves to protect hands).
- Keep waste streams separate if possible. It is much easier to keep track of solvent flows if waste coatings, etc are not mixed; what goes in is then the same as what comes out.
- If mixed, analyse wastes occasionally. The amount of solvent/solids in a substance can be determined by weighing a sample before and after solvent evaporation (see Process Guidance Note PG6/23A *Coating of metal and plastic* for a detailed description which is given on the Defra website www.defra.gov.uk/environment/ and the Environment Agency website www.environment-agency.gov.uk).
- Estimate other losses. In some cases, it is best to base estimates on simple experiments, eg capturing washings to drain and analysing them for solvent content.

This section of the Guide provides advice on:

- how to take account of varying production levels;
- how to plot useful graphs and interpret them to identify problems and potential causes;
- using the computer spreadsheet provided with this Guide (see **section 6**) to semi-automate the mass balance and analysis process.

Simple analysis of your collated data (particularly an examination of solvent consumption patterns) allows you to:

- focus on the real problems quickly;
- eliminate variations caused by production changes;
- present the data in a format that is easier to interpret;
- provide feedback on progress and highlight the benefits of solvent management to other managers.

4.1 The importance of production volumes

When considering the efficiency of solvent use, calculated solvent quantities are of limited value as they vary in response to production volume changes as well as to good/bad solvent management practices. However, if calculated solvent quantities can be linked to production throughput over the same time period, the figures can show real trends in solvent consumption from month to month and from process to process. This, in turn, makes poor practices, such as leaks, easier to detect and the effects of new solvent reduction techniques easier to demonstrate.

When analysing your solvent data, it is essential to relate emissions (E) to production throughput (P) for the same period as used for the solvent data, ie E/P.

The unit of production should be chosen carefully to allow meaningful comparisons. This is not a problem when a site produces only one type of product, eg a shoe manufacturer that makes one style of shoe can use 'pairs of shoes' as a production indicator.

When a company produces a range of products, the amount of solvent used each month will vary. The solvent manager should choose the most appropriate indicator for the site's particular characteristics. Indicators can be:

- direct measures, eg as m² of surface covered;
- indirect measures, eg number of jobs, job hours or sales value.

4.1.1 Example of accounting for production throughput

A vehicle refinishing paint shop carries out a wide variety of jobs during any month, ranging from the respraying of whole cars through respraying wings, doors and bumpers to small dent repairs. The total number of jobs also varies significantly from month to month. The company wants to eliminate the natural/expected variation caused by throughput changes, both to make sense of its paint/solvent use and to track progress in reducing consumption. It therefore considered how best to keep track of 'throughput' to help achieve these objectives.

In this situation, the best approach is to use factors for each type of job. If a complete respray is considered equivalent to 100 units, all other job types can be allocated a number of units which are proportional to the size of the job. In this way, total production can be more meaningfully measured as number of units. The example shown in Table 5 gives a total of 368 units during the period of interest. This equates to almost 3.7 complete resprays - a far more meaningful measure than 11 'jobs'.

Table 5 Accounting for changes in production throughput at a vehicle refinisher

Job type	Number of jobs in period	Number of units per job	Total units in period
Complete respray	3	100	300
Front wing	4	8	32
Bonnet	1	16	16
Doors	2	8	16
Bumper/grill	1	4	4
Total	11		368

Such data can help you to look at the change in solvent emissions on a month-by-month basis and to compare one similar process with another (eg two spray booths). You can also ask questions such as:

- Is E/P reducing over time? Is there potential for further improvement?
- How does E/P compare from one booth to another?
 - Should they be similar (eg same process/equipment)?
 - Is the variation normal or is there a problem?
 - Is it possible to identify the good practice that is creating the lower losses?

4.2 Simple graphical techniques

Solvent and material use data should be analysed with the aims of:

- improving efficiency;
- saving money;
- meeting the requirements of pollution control legislation.

The best way of analysing your data is to prepare graphs. The use of a computerised spreadsheet allows a simple graphical presentation to be produced, which is particularly useful when trying to convince other managers that steps should be taken to improve solvent management. Graphs and pie charts can also be used to inform and motivate employees, providing a clear stimulus for co-operation and action.

Once trends and patterns have been plotted, possibilities for improvement can be investigated in a systematic way to establish the real issues and problems. Brainstorming sessions can be useful at this stage. Make sure you involve all relevant staff in these investigations, including shop-floor staff who are often in the best position to help with constructive comments and suggestions.

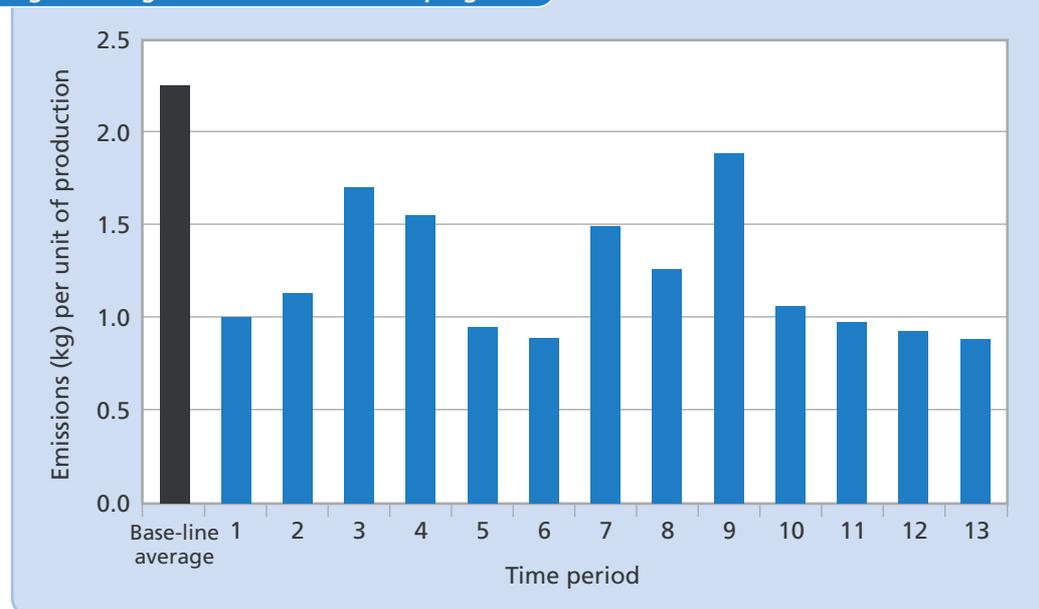
Good Practice Guide *Measuring to manage: the key to reducing waste costs* (GG414)¹³ gives more detailed advice on data analysis.

¹³ Available free of charge through the Environment and Energy Helpline on freephone 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

4.2.1 Bar charts

The best approach generally involves the use of graphs such as the simple bar chart shown in Fig 10 in which a comparison is made against a 'base-line' average or mean. While the graph shows there has been great improvement, there is considerable variation over the year with particularly high levels of relative consumption (per unit of production) in periods 3, 4, 7 (possibly 8) and 9.

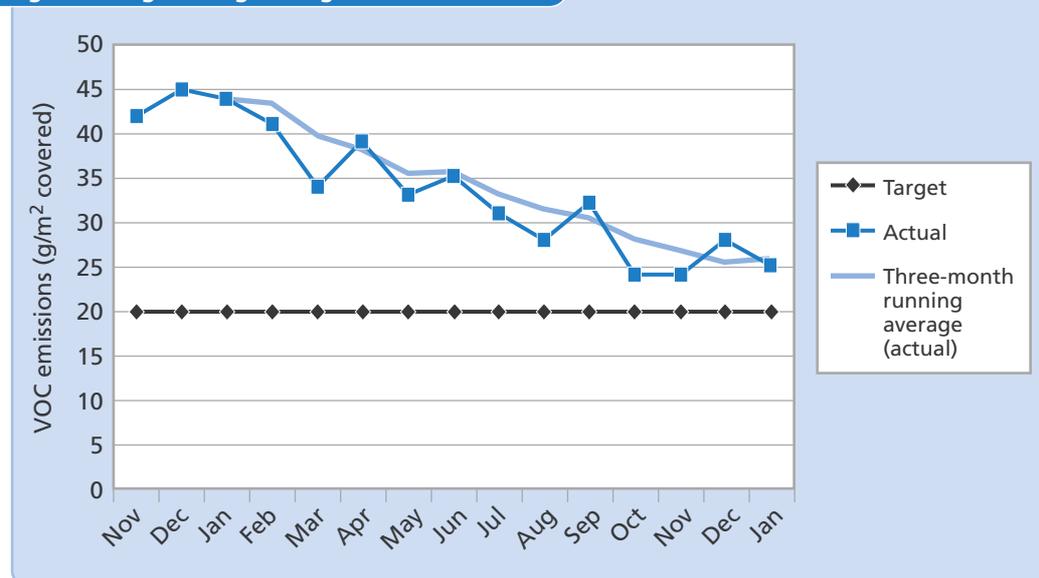
Fig 10 Using a bar chart to monitor progress



4.2.2 Trend graphs

It is also useful to look at trends. Fig 11 shows progress towards a target of emissions of 20 g/m². The raw data show significant variations from month to month, but the three-month running average gives a more reassuring trend, albeit one that is perhaps levelling-off above the target level. This trend line is merely a plot of the mean of the three months prior to and including the present one, ie 3,2,1; 4,3,2; 5,4,3; etc.

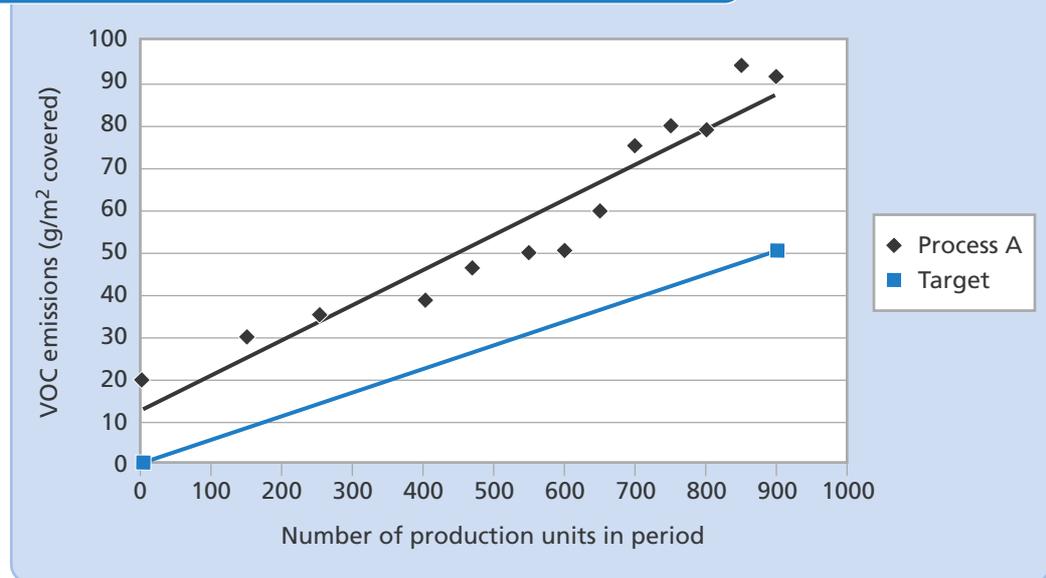
Fig 11 Using moving averages to show trends



4.2.3 Scatter graphs

You can also plot data as a scatter graph (see Fig 12). With scatter graphs, production units are plotted on the x-axis and solvent emissions (or another parameter of interest) on the y-axis. The various time periods are therefore 'scattered' about rather than ordered chronologically as in a normal graph.

Fig 12 Scatter plot of VOC emissions versus production units



A line-of-best-fit (in this case a 'least squares' regression line¹⁴) can be drawn through the data to show the trend. As in Fig 12, this is normally a straight line.

The equation for a straight line is: $y = mx + c$

where: m = gradient of the line
 c = intercept value, ie the value of y at which $x = 0$.

- The gradient indicates the efficiency; in this case, how much extra solvent it takes for one more unit of production.
- The intercept indicates the 'fixed' load at zero production. If the data imply significant consumption at zero production, this raises questions such as: 'Is there a leak from a tank or pipe that has nothing to do with the level of production?'
- The amount of scatter about either side of the line indicates the level of variation (related to the standard deviation).

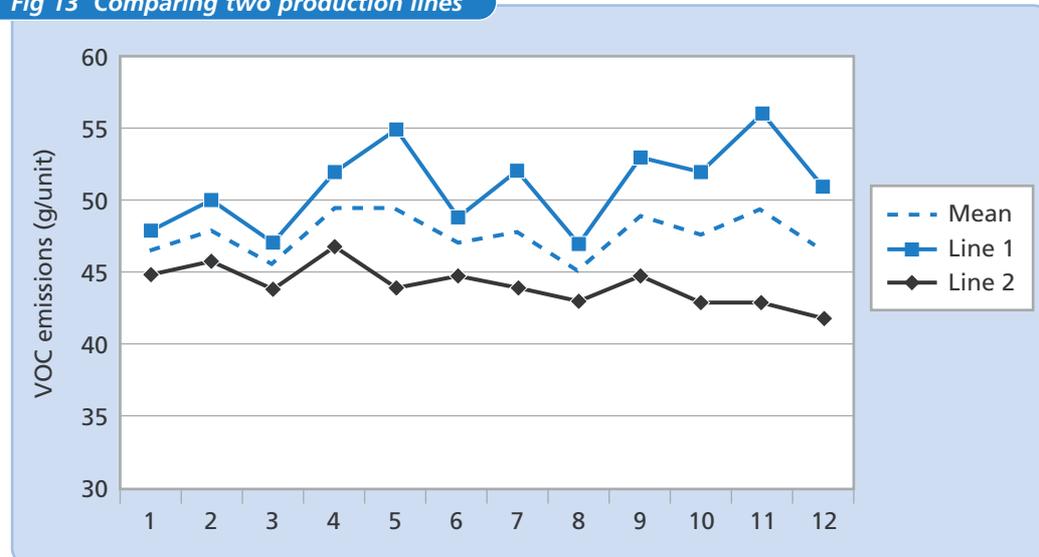
The example in Fig 12 shows actual solvent use some way above the target level. One reason for this is the high 'fixed' load at zero production; this may be due to a leak, although the process is also less efficient than the target (the former has a steeper line). It can also be seen that the process is at its most efficient in terms of solvent use at a production rate between 400 to 700 units, with higher rates of use above and below these levels. Various equipment-related or human factors could be at play here and further investigation is likely to be worthwhile.

4.2.4 Making comparisons

You can also make internal comparisons, eg by looking at different parts of the manufacturing process (as in Fig 13 overleaf) or different time periods. This example shows data for two production lines and the average or arithmetic mean.

¹⁴ Microsoft® Excel and other software packages can draw a linear regression line through a set of data on a graph.

Fig 13 Comparing two production lines



In the example in Fig 13, just keeping track of the mean for the two lines would suggest that solvent use was reasonably under control and was always between 45 g/unit and 50 g/unit. However, looking at the two production lines in isolation shows that Line 2 has little variation (ie it is 'under control') and solvent use is gradually falling, while Line 1 has a lot of variation (ie it is 'out of control') and solvent use is increasing.

Using means (or any aggregated data) can conceal problems at the process level. In this example, it is necessary to investigate the causes of both the higher overall use and the significant variations on Line 1. If the lines are similar in terms of their equipment, then the differences must relate to factors such as equipment set-up, maintenance, operator practices, etc. If the problems can be identified and fixed, Line 1 should perform as well as Line 2. More information on process control can be found in *Preventing waste in production: practical methods for process control* (GG224) and *Preventing waste in production: industry examples* (GG223). Both publications are available free of charge through the Environment and Energy Helpline on 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

4.3 Using a computer spreadsheet

Using a computer spreadsheet makes the task of recording and analysing solvent data much easier and faster. The disk supplied with this Guide contains spreadsheet files to help you record and analyse your data. Example and blank workbooks, gg429 example.xls and gg429 blank.xls, are provided in Microsoft® Excel 97.

If you use spreadsheet software other than Excel or a different version of Excel, please contact the Environment and Energy Helpline on 0800 585794. If possible, the Helpline will send you the spreadsheet in your required format. Instructions on how to use the spreadsheets are contained within the electronic files and given in **section 6** of this Guide.

Alternatively, you can use the advice given in this Guide to develop appropriate spreadsheets on paper or in a different computer format for your company.

4.4 Practical measures to reduce solvent use/emissions

A wide variety of solutions may be appropriate to your specific solvent management challenges. Detailed practical advice, applicable to different industry sectors, is given in other Envirowise publications. These can be obtained by calling the Environment and Energy Helpline on 0800 585794 or by visiting the Envirowise website (www.envirowise.gov.uk).

Good Practice Guide *Reducing solvent use by good housekeeping* (GG413)¹⁵ provides information on a wide range of practical measures. It is relevant to companies of all sizes seeking a cost-effective way of:

- improving resource efficiency;
- reducing solvent consumption to comply with legislation;
- meeting the objectives and targets set by quality management systems such as the ISO 9000 series and environmental management systems such as ISO 14001 and EMAS.

New spraying equipment reduces coating costs

Advanced Colour Coatings, based in Birmingham, was established over 30 years ago and currently employs 42 people. The company is a specialist applicator of pretreatment, paints and powder coatings for substrates used within a wide range of sectors including the automotive and electronics industries. Its commitment to quality, environmental and social responsibilities is reflected in the company's certification to QS 9000, ISO 9002, ISO 14001 and Investor-in-People standards.

The company has a philosophy of continuous improvement throughout all areas of the business. This philosophy has led to an investment in new spraying and coating equipment which has reduced powder usage costs by £26 000/year and provided a payback period of just six months.

¹⁵ Available free of charge through the Environment and Energy Helpline on freephone 0800 585794 or via the Envirowise website (www.envirowise.gov.uk).

Systematic solvent management can help you to save money and comply with environmental legislation more cost-effectively. It also has many other benefits in terms of environmental risk, health and safety, and company reputation.

For successful solvent management:

- ✓ Carry out an initial review to identify the scope of potential cost savings and opportunities for improvement.
- ✓ Obtain commitment from senior management for a systematic solvent management programme.
- ✓ Set up a team or teams to carry out the work involved. Make an appropriate 'champion' responsible for investigating solvent management issues and give them the resources (time, people, access, etc) to do the job properly.
- ✓ Gather data on your company's use of organic solvents and materials containing solvents at a site level and for individual processes.
- ✓ Use these data to prepare a mass balance. This will help you to understand how much solvent is being used, emitted and wasted. It may also highlight opportunities for reducing solvent use and VOC emissions.
- ✓ Analyse your data using graphs to show trends and variations in solvent use.
- ✓ Investigate potential problems and identify the causes of waste and unnecessary emissions.
- ✓ Contact the Helpline or visit the Envirowise website (www.envirowise.gov.uk) to order free Envirowise publications describing practical measures relevant to your sector.
- ✓ Consider possible improvement options and prioritise them in terms of costs, benefits and practicality.
- ✓ Implement no-cost and low-cost measures (eg good housekeeping) which offer immediate or rapid cost savings and other benefits.
- ✓ Produce and implement an action plan with appropriate objectives, targets and actions. Involve shop-floor staff as well as managers.
- ✓ Review progress in terms of reductions in solvent use/emissions and in terms of how well the solvent management programme is working.

5.1 Free help and information from Envirowise

Contact the Environment and Energy Helpline on 0800 585794 or visit the Envirowise website (www.envirowise.gov.uk) to:

- find out about free Envirowise publications relevant to your operations;
- seek free advice from an Envirowise expert, eg about environmental legislation applicable to your site;
- request a *FastTrack* visit (a confidential, on-site waste review carried out by an environmental advisor and including up to a day's free advice)¹⁶;

¹⁶ This service is available to UK companies with fewer than 250 employees.

- ask about a counselling visit from an Envirowise consultant to discuss a specific environmental issue at your site.

The following Envirowise guides offer practical advice that is applicable to companies in all sectors:

- *Solvent capture for recovery and re-use from solvent-laden gas streams* (GG12)
- *Reducing solvent use by good housekeeping* (GG413)
- *Cost-effective reduction of fugitive solvent emissions* (GG71)
- *Solvent capture and recovery in practice: industry examples* (GG100)
- *Solvent management in practice: industry examples* (GG124)
- *Monitoring VOC emissions: choosing the best option* (GG203)
- *Surface cleaning and preparation: choosing the best option* (GG354)
- *Cost-effective paint and powder coating: materials management* (GG385)
- *Cost-effective paint and powder coating: coating materials* (GG386)
- *Cost-effective paint and powder coating: application technology* (GG387).

A range of free Envirowise publications on solvent management in various sectors is also available. Like all Envirowise publications, these can be downloaded from the website (www.envirowise.gov.uk). You may find it useful to visit the solvents and VOCs area of the website.

Systematic approach helps company save money and comply with LAPC targets

In 1995, Bovince Limited was set year-on-year targets by its local authority to reduce VOC emissions from its screen printing operations. Implementation of an environmental management system (EMS) has helped the company remain comfortably ahead of its regulatory targets every year.

Adoption of good housekeeping practices and the introduction of ultraviolet printing inks for as many jobs as possible have reduced the amount of solvent required. By 2001, these activities had resulted in the company reducing its solvent consumption by 50% compared with 1996 levels.

The company achieved solvent cost savings of £61 600 between 1996 and 2000.

Computer spreadsheet for tracking solvent use

The disk supplied with this Guide contains two spreadsheets in Microsoft® Excel 97: gg429 example.xls and gg429 blank.xls. Copy these files into an appropriate directory on your computer and then look at the file gg429 example.xls, together with the accompanying notes and this section. The file gg429 blank.xls is for you to record and analyse your own input and output data. This file can be copied and renamed as you wish. If you don't have access to Excel 97 (or other versions of Excel), contact the Environment and Energy Helpline on 0800 585794 for advice.

The spreadsheet contains all the necessary formulae and will calculate your solvent emissions and solvent mass balance automatically. Once you have entered your production figures for the corresponding time periods, the spreadsheet will also calculate your solvent emissions per production unit.

In addition to using the spreadsheet to identify opportunities for reducing solvent emissions, you can use a print-out of the Mass Balance worksheet to submit information about your site's annual solvent emissions to your regulator. A print-out of the Materials worksheet will provide a list of your solvent-containing materials.

The Excel spreadsheet is broken down into several worksheets within a single workbook. You can navigate between worksheets by clicking on the labelled tabs at the bottom of the screen. If you click on a tab to open a worksheet and the screen appears blank, you can jump to the top of the screen using the keyboard shortcut Ctrl + Home. The table or graph will then come into view. The screens have been designed so that you only need to scroll up and down.

When adding your own data, you only need to fill in the white cells - the yellow cells contain formulae and will be filled in automatically.

Before you start entering your data, you are advised to spend some time reading the rest of this section and looking at the example spreadsheet on the attached disk. This spreadsheet contains data from a fictitious printing company that uses six inks with different solvent contents and two cleaning solvents.

The following sections correspond with the worksheet tabs in the spreadsheet.

6.1 Instructions

Before starting to use the spreadsheet, print out and read the Instructions worksheets from gg429 blank.xls and gg429 example.xls.

6.2 Materials

The first step is to fill in details of the materials you use on the Materials worksheet (see Fig 14 overleaf). Click on the Materials tab at the bottom of the workbook.

Enter the solvent description, supplier, supplier's product code and solvent content in the cells provided. Note that solvent content should be calculated in kg/litre.

If you use a number of materials that all have the same solvent content, then they can be grouped together. For example, if three inks have the same solvent content, then just have a description 'ink' in the Solvent Description column.



If the solvent content of a material changes, then it will be necessary to treat it as a separate material.

If you have more than eight materials, see the Instructions worksheet print-out for details of how to add additional materials to the tables.

Fig 14 Table 1 from the Materials worksheet in gg429 example.xls

Materials See section 6.2 of the Guide for details of how to use this worksheet

Table 1 List of materials used

Material	Solvent description	Supplier	Supplier product code	Solvent content (kg/litre)
1	Ink	Ink & Co	IC001	0.80
2	Ink	Ink & Co	IC002	0.60
3	Ink	Ink & Co	IC003	0.70
4	Ink	Ink & Co	IC004	0.65
5	Ink	Printing Supplies	PS001	0.50
6	Ink	Printing Supplies	PS002	0.40
7	Cleaning solvent	Solvent Ltd	SL001	1.00
8	Cleaning solvent	Solvent Ltd	SL002	0.90

6.2.1 Hints and tips

- List each material separately; you may have more than eight. To add further rows, see the Instructions worksheet in gg429 blank.xls for step-by-step guidance.
- If in doubt about the solvent content, see **sections 3.1.2** and **3.1.3** and, if necessary, check with your supplier.
- The spreadsheet allows you to include reference data for each material; an example is shown in Fig 14 and includes details such as the solvent supplier and the supplier product code.
- Listing the supplier and supplier's product code will help you to identify materials, but it is not critical to the mass balance.

6.3 Base data entry

You can now enter the data you want to use for base-line comparison (ie before starting your solvent management programme) on the Base Data Entry worksheet (see Fig 15).

To ensure a representative base position, data from six time periods are required for each solvent-containing material; the spreadsheet is designed to work with this number of data periods.

If data are not available, estimates can be entered and the spreadsheet updated when sufficient base data are available.

The spreadsheet will then calculate the total solvent input, output and emissions for each period and relate them to production during that period.

If you wish to compare performance against output, you also need to enter the measure of production. Go to the Mass Balance worksheet (see Fig 17) and, on Table 4, insert production units for time periods 1 - 6. Production measures are described in **section 4.1** of the Guide.

Fig 15 Part of Table 2 from the Base Data Entry worksheet in gg429 example.xls

Base Data Entry See section 6.3 of the Guide for details of how to use this worksheet**Table 2**

Solvent containing material 1

Time period	Material description:				Waste/product description:				Waste ink		Emissions (kg)
	Initial stock (litres)	Material purchased (litres)	Final stock (litres)	Solvent content (kg/litre)	Input (kg)	Initial waste/product (litres)	Waste disposals/product sales (litres)	Final waste/product (litres)	Solvent content (kg/litre)	Output (kg)	
1	5.00	80.00	8.00	0.80	61.60	2.00	30.00	3.00	0.80	24.80	36.80
2	8.00	75.00	7.00	0.80	60.80	3.00	27.00	4.00	0.80	22.40	38.40
3	7.00	100.00	12.00	0.80	76.00	4.00	29.00	2.00	0.80	21.60	54.40
4	12.00	120.00	15.00	0.80	93.60	2.00	45.00	5.00	0.80	38.40	55.20
5	15.00	90.00	10.00	0.80	76.00	5.00	40.00	4.00	0.80	31.20	44.80
6	10.00	65.00	5.00	0.80	56.00	4.00	15.00	2.00	0.80	10.40	45.60

6.3.1 Hints and tips

- You can add the waste or product description to the white box in the top bar of each table.
- You can select the time period to suit your operation. Time period 1 could be a month, a week or a day. The time period should be consistent for each material.
- Some definitions of the table headings are given below. For more information on how to calculate inputs and outputs, see **section 3**.
 - **Initial stock** is how much of the material you had at the start of each time period. This is filled in automatically after the first time period.
 - **Material purchased** is the amount of new material (in litres) that is issued/introduced during the period.
 - **Input** is the total amount of solvent input to your process in each material.
 - **Initial waste/product** is the amount of waste that contains solvent that is to be disposed of (or is in storage before disposal), plus the amount of product containing solvent awaiting dispatch.
 - **Waste disposals/product sales** records the amount of waste that contains solvent that has been disposed of, plus the amount of product containing solvent that has been dispatched.
 - **Final waste/product** is the amount of waste and product containing solvent that, at the end of the period, has yet to be disposed of and dispatched.
 - **Solvent content** is the amount of solvent in kg/litre of material. You may need to estimate this for your different waste streams.
- If in doubt, estimate; you can always update the values on the spreadsheet later.

6.4 Current data entry

You can now start to input data for each subsequent time period. Fig 16 shows a completed version of this worksheet following 13 time periods. These current data points are plotted automatically on the scatter graphs in the workbook, allowing you to check performance compared with the base-line.

To allow comparison against production, you will need to enter the units of production for the time period in Table 5 (see Fig 17) on the Mass Balance worksheet. Production measures are described in **section 4.1** of the Guide.

Fig 16 Part of Table 3 from the Current Data Entry worksheet in gg429 example.xls

Current Data Entry See section 6.4 of the Guide for details of how to use this worksheet**Table 3**
Solvent containing material 1

Material description:				Waste/product description:				Waste ink			
Time period	Initial stock (litres)	Material purchased (litres)	Final stock (litres)	Solvent content (kg/litre)	Input (kg)	Initial waste/product (litres)	Waste disposals/product sales (litres)	Final waste/product (litres)	Solvent content (kg/litre)	Output (kg)	Emissions (kg)
1	5.00	60.00	8.00	0.80	45.60	2.00	20.00	5.00	0.80	18.40	27.20
2	8.00	60.00	5.00	0.80	50.40	5.00	10.00	5.00	0.80	8.00	42.40
3	5.00	45.00	6.00	0.80	35.20	5.00	12.00	2.00	0.80	7.20	28.00
4	6.00	55.00	7.00	0.80	43.20	2.00	10.00	0.00	0.80	6.40	36.80
5	7.00	80.00	3.00	0.80	67.20	0.00	8.00	2.00	0.80	8.00	59.20
6	3.00	85.00	5.00	0.80	66.40	2.00	12.00	1.00	0.80	8.80	57.60
7	5.00	60.00	8.00	0.80	45.60	1.00	10.00	3.00	0.80	9.60	36.00
8	8.00	65.00	5.00	0.80	54.40	3.00	15.00	2.00	0.80	11.20	43.20
9	5.00	40.00	6.00	0.80	31.20	2.00	20.00	2.00	0.80	16.00	15.20
10	6.00	60.00	8.00	0.80	46.40	2.00	18.00	1.00	0.80	13.60	32.80
11	8.00	80.00	11.00	0.80	61.60	1.00	20.00	3.00	0.80	17.60	44.00
12	11.00	85.00	12.00	0.80	67.20	3.00	12.00	4.00	0.80	10.40	56.80
13	12.00	90.00	4.00	0.80	78.40	4.00	10.00	2.00	0.80	6.40	72.00
Totals		865.00			692.80		177.00			141.60	551.20

6.4.1 Hints and tips

As you enter data at the end of the time period, the spreadsheet will automatically work out performance compared with the base-line.

Remember that you need to complete records for each solvent-containing material.

6.5 Mass balance

The Mass Balance worksheet will calculate the emissions for all solvents (see Fig 17). These data are of limited use unless they can be related to an appropriate production measure. To relate emissions to production, fill in your production figures for the corresponding time periods in Tables 4 and 5 of the Mass Balance worksheet.

The chosen production indicator must be measured over the same time period as that for solvent inputs and outputs.

When comparing processes or departments, it is best to consider the output from that process or department rather than from the site as a whole. Direct production measures could include:

- number of items coated or cleaned per week;
- area coated or cleaned per week;
- volume of coating manufactured.

Indirect measures could include:

- number of production hours per week;
- number of operating hours per week;
- value of production in a batch.

Where known factors alter the quantity of solvent used (eg a printing substrate or the product design), the production measure should be adjusted to compensate. For example, if a different substrate is known to require 20% more ink than the usual substrate, the production figure should be multiplied by 1.2.

Inputs, outputs and emissions can all be related to the production measure, eg kilograms of solvent per car resprayed or grams of solvent used for each printing screen cleaned.

Fig 17 Tables 4 and 5 from the Mass Balance worksheet in gg429 example.xls

Mass Balance See section 6.5 of the Guide for details of how to use this worksheet

Table 4 Base data

Time period	Input (kg)	Output (kg)	Emitted (kg)	Production units	Input/production (kg)	Output/production (kg)	Emitted/production (kg)
1	1144.20	354.50	789.70	500.00	2.29	0.71	1.58
2	1174.95	364.60	810.35	450.00	2.61	0.81	1.80
3	781.95	282.40	499.55	250.00	3.13	1.13	2.00
4	1188.80	380.50	808.30	680.00	1.75	0.56	1.19
5	927.20	287.30	639.90	150.00	6.18	1.92	4.27
6	939.35	268.10	671.25	250.00	3.76	1.07	2.69
Average	1026.08	322.90	703.18	380.00	3.29	1.03	2.25
Totals	6156.45	1937.40	4219.05	2280.00			

Table 5 Current data

Time period	Input (kg)	Output (kg)	Emitted (kg)	Production units	Input/production (kg)	Output/production (kg)	Emitted/production (kg)
1	945.40	291.50	653.90	650.00	1.45	0.45	1.01
2	870.50	292.50	578.00	510.00	1.71	0.57	1.13
3	731.70	211.90	519.80	305.00	2.40	0.69	1.70
4	876.00	294.30	581.70	375.00	2.34	0.78	1.55
5	982.10	329.10	653.00	690.00	1.42	0.48	0.95
6	1047.60	354.90	692.70	780.00	1.34	0.46	0.89
7	912.40	247.20	665.20	445.00	2.05	0.56	1.49
8	881.10	236.00	645.10	510.00	1.73	0.46	1.26
9	658.70	187.70	471.00	250.00	2.63	0.75	1.88
10	884.70	249.40	635.30	595.00	1.49	0.42	1.07
11	971.80	339.00	632.80	650.00	1.50	0.52	0.97
12	1067.70	395.50	672.20	725.00	1.47	0.55	0.93
13	1074.90	381.50	693.40	780.00	1.38	0.49	0.89
Average	915.74	293.12	622.62	558.85	1.76	0.55	1.21
Totals	11904.60	3810.50	8094.10	7265.00			

6.6 Performance charts

The example spreadsheet on the computer disk supplied with this Guide demonstrates the use of scatter plots and bar charts to relate solvent use to a production measure (see Fig 18 overleaf). Similar graphs are produced automatically when you enter your data in the blank spreadsheet.

Click on the remaining tabs to view the graphs that have been produced. Titles, axes and line labelling can be altered as required. The graphs are labelled as follows:

- **Plot I - P** - scatter plot of solvent input versus number of production units;
- **Plot O - P** - scatter plot of solvent output versus number of production units;
- **Plot E - P** - scatter plot of solvent emissions versus number of production units;
- **IP - time** - solvent input per unit of production;
- **OP - time** - solvent output per unit of production;
- **EP - time** - solvent emissions per unit of production.

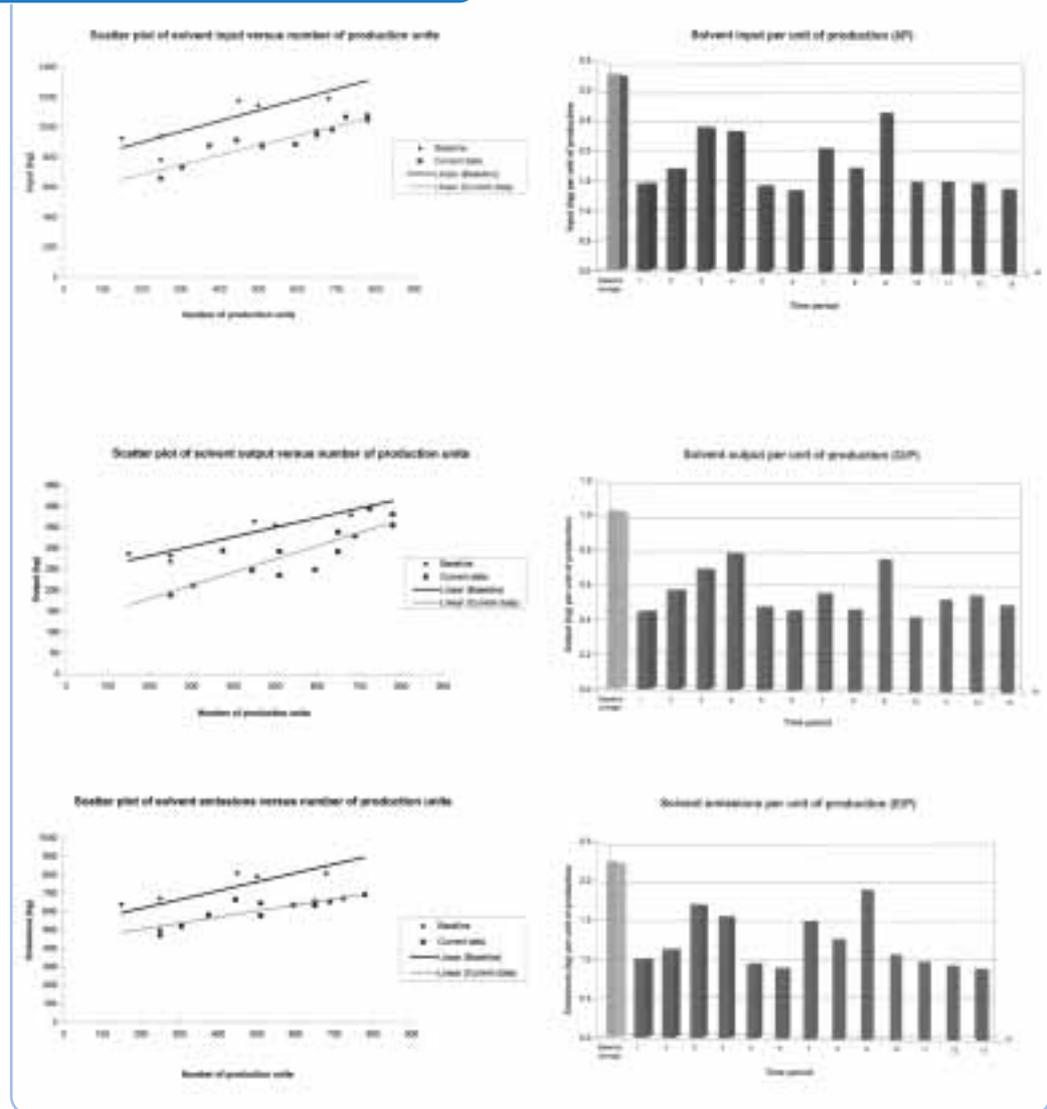
The spreadsheet plots scatter graphs of solvent input, output and emissions versus the number of production units. The line of best fit is drawn by the computer through the base data and can be used as the base-line against which progress can be assessed; the aim is to move as far below this base-line as possible.

If a new point is below the line of best fit, this shows that performance has improved during that time period. However, if the new point is above the base-line, performance is worse. You can also use the bar charts of solvent input, output and emissions per production unit to identify periods with the highest waste.

Production-adjusted figures allow you to monitor changes from month-to-month and from process-to-process. Leaks, poor operator practices, etc should then be easier to detect.

It is possible to create other performance charts, eg comparing individual processes or comparing day shifts to night shifts, but these are beyond the scope of this Guide.

Fig 18 Charts from gg429 example.xls



6.7 Printing

Individual pages, worksheets or the complete workbook can be printed from Excel in the normal way. The data can be used to aid your compliance reporting and for internal purposes such as helping to motivate staff and to inform senior managers about progress.

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Envirowise - Practical Environmental Advice for Business - is a Government programme that offers free, independent and practical advice to UK businesses to reduce waste at source and increase profits. It is managed by Momenta, an operating division of AEA Technology plc, and Technology Transfer and Innovation Ltd.

Envirowise offers a range of free services including:

- ✔ Free advice from Envirowise experts through the Environment and Energy Helpline.
- ✔ A variety of publications that provide up-to-date information on waste minimisation issues, methods and successes.
- ✔ Free, on-site waste reviews from Envirowise advisors, called *FastTrack* visits, that help businesses identify and realise savings.
- ✔ Guidance on waste minimisation clubs across the UK that provide a chance for local companies to meet regularly and share best practices in waste minimisation.
- ✔ Best practice seminars and practical workshops that offer an ideal way to examine waste minimisation issues and discuss opportunities and methodologies.



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