

IAMC Toolkit

Innovative Approaches for the Sound Management
of Chemicals and Chemical Waste



Technical Manual Paint and Varnishes Industry

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Masthead

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1 Introduction

The United Nations Industrial Development Organization's (UNIDO) overarching objective is to reduce poverty through sustainable industrial development. In response to this global challenge, UNIDO launched the **Green Industry** initiative with the aim of fostering the positive role of industry in achieving sustainable economic growth. According to UNIDO's Green Industry vision, the industries' role is to constantly providing creative and innovative solutions and alternatives to countries' economies, focusing on a well-balanced economic, environmental and social impact of industry. Sustainable development has indeed become a core determinant of economic competitiveness and allows industries to decouple their economic growth and revenues from excessive and increasing resource use and pollution by minimizing waste in every form, using renewable resources, taking precautions to avoid harming workers, communities as well as the environment [1].

The joint global **UNIDO-UNEP Resource Efficient and Cleaner Production (RECP) Program** endorses the Green Industry vision. The program is based on a multi-pronged programmatically- and geographically-focused approach to scale-up and mainstream the application of RECP concepts, methods, techniques, technologies and policies in developing and transition countries in order to improve resource efficiency and environmental performance of enterprises and other organizations, in particular small and medium sized operators in the manufacturing and associated sectors.

The multi-faceted reliance on chemicals across industries makes chemicals production to one of the major and most globalized industrial sectors with a high impact on the overall sustainability performance of supply chains. The essential economic role of chemicals and their contribution to improved living standards needs to be balanced under consideration of all potential costs. An adequate cost analysis thus has to include the **chemical industry's use of resources**, such as water and energy, and the potential adverse impacts of chemicals on the environment and human health. Taking into consideration the potential severity and complexity of such impacts, highlights the fact that sound chemicals management is a key issue for sustainable development [2].

Under this program, the project entitled **Innovative Approaches for the Sound Management of Chemicals and Chemical Waste** aims at providing three groups of industries namely producers of chemicals, formulators and industrial users of chemical products with innovative approaches and specific technical solutions to chemicals and chemical waste management. The main target is to achieve a reduction of chemical consumption in both production and application of chemicals. Further targets also address the replacement of hazardous chemicals by chemicals with a lower risk, the reduction of chemical wastes, the safe handling of chemicals and risk reduction related to accidents with chemicals. In each of the 5 participating countries (as of 2013: Colombia, Egypt, El Salvador, Morocco and Peru) and the three groups of industries concerned by the project, the identification and implementation of innovative alternatives and solutions is made on a subsector basis (i.e. industries in the paint formulation, paint application, textile finishing and polymers domains). Assessments in subsectors in each of the participating countries led to the development of the present **technical manual**, which aims at triggering innovative ideas, providing cost-effective innovative solutions and at enabling companies in these countries and subsectors to implement environmentally sound management of chemicals and chemical waste with high impact.

Introducción

El principal objetivo de la Organización de las Naciones Unidas para el Desarrollo Industrial (ONUDI) es reducir la pobreza por medio del desarrollo industrial sostenible. En respuesta a este desafío global, ONUDI lanzó la iniciativa *Industria Verde* con el objetivo de promover el papel positivo de la industria a la hora de conseguir un crecimiento económico sostenible. Según la visión de la Industria Verde de ONUDI, el papel de las industrias es el de ofrecer constantemente soluciones y alternativas creativas e innovadoras a las economías de los países, centrándose en un impacto social de la industria bien equilibrado, económico y medioambiental. De hecho, el desarrollo sostenible se ha convertido en un factor decisivo central de la competitividad económica y permite a las industrias separar su crecimiento económico y sus ingresos del uso de recursos excesivo y creciente y de la contaminación, así como minimizando el gasto en todas las formas, usando recursos renovables, tomando precauciones para evitar dañar a los trabajadores, así como a las comunidades y al medioambiente [1].

El *Programa ONUDI-PNUMA para la Eficiencia en el uso de Recursos y Producción Más Limpia (RECP)* respalda la visión de la Industria Verde. El programa está basado en una estrategia multilateral con enfoque programático y geográfico para aumentar y hacer prevalecer la aplicación de los conceptos, métodos, técnicas, tecnologías y políticas RECP en los países en desarrollo y en transición. El objetivo es de mejorar la eficiencia en el uso de los recursos y el rendimiento medioambiental de las empresas, con especial enfoque a los medianos y pequeños operadores de los sectores manufactureros y asociados.

La interdependencia de las industrias en relación con las sustancias químicas a lo largo de las industrias hace que la producción de sustancias químicas sea uno de los mayores sectores industriales y más globalizados con un alto impacto sobre el rendimiento global de la sostenibilidad de las cadenas de suministro. El papel económico esencial de las sustancias químicas y su contribución a la mejora del nivel de vida debe ser equilibrado considerando todos los costes potenciales. Así, un análisis de costes adecuado debe incluir el **uso de recursos por la industria química** como el agua y la energía, así como los impactos potenciales adversos de las sustancias químicas sobre el medioambiente y la salud humana. Teniendo en cuenta la potencial severidad y complejidad de dichos impactos, subraya el hecho de que la buena gestión de las sustancias químicas constituye un factor clave para el desarrollo sostenible [2].

Bajo este programa, el proyecto titulado *Enfoques Innovadores para una Buena Gestión de las Sustancias y de los Desechos Químicos* pretende ofrecer a tres grupos de industrias, en concreto a los productores de sustancias químicas, a los formuladores y a los usuarios industriales de productos químicos, enfoques innovadores y soluciones técnicas específicas a la gestión de sustancias y desechos químicos. El principal objetivo es lograr una reducción del consumo de sustancias químicas tanto en su producción como en su aplicación. Además, se pretende afrontar la sustitución de sustancias químicas peligrosas por sustancias químicas de menor riesgo, la reducción de los desechos químicos y el tratamiento seguro de sustancias químicas y la reducción de riesgos relacionados con los accidentes con sustancias químicas. En cada uno de los 5 países participantes (en 2013: Colombia, Egipto, El Salvador, Marruecos y Perú) y en los tres grupos de industrias interesados en el proyecto, la identificación y la implementación de alternativas y soluciones innovadoras se realiza sobre una base subsectorial (es decir, industrias de formulación y aplicación de pinturas, acabado de textiles y polímeros). Las evaluaciones en subsectores en cada uno de los países participantes condujo al desarrollo del presente *manual técnico* que pretende desencadenar ideas innovadoras, ofreciendo soluciones innovadoras efectivas a nivel de costes y permitiendo a las empresas y a los subsectores en estos países implementar una buena gestión medioambiental de las sustancias y desechos químicos con un gran impacto.

Introduction

L'objectif prioritaire de l'Organisation des Nations Unies pour le développement industriel (ONUDI) est de réduire la pauvreté à l'aide du développement industriel durable. Pour répondre à ce défi mondial, l'ONUDI a lancé l'initiative en faveur de *l'industrie verte (Green Industry)* dans le but de promouvoir le rôle positif de l'industrie dans la croissance économique durable. Selon la vision de l'industrie verte de l'ONUDI, le rôle des industries est de fournir en permanence des solutions et des alternatives créatives et innovantes aux économies des pays, en recherchant un équilibre entre les impacts économiques, environnementaux et sociaux. Le développement durable est en effet devenu un facteur déterminant de la compétitivité économique et permet aux industries d'assurer la croissance économique et les revenus, tout en limitant la pollution et l'utilisation excessive des ressources, en réduisant toutes les formes de déchets, en utilisant des ressources renouvelables et en prenant des précautions pour éviter de nuire aux travailleurs, aux communautés et à l'environnement [11].

Le *Programme mondial commun de production propre et économe en ressources (PCER) de l'ONUDI-PNUE* sanctionne la vision de l'industrie verte. Le programme est basé sur une approche à plusieurs volets dont les objectifs (en termes de contenu et de géographie) sont d'étendre et d'intégrer l'application des concepts, méthodes, techniques, technologies et politiques du PCER dans les pays en développement et en transition. Le programme vise à améliorer l'efficacité des ressources et la performance environnementale des entreprises et des autres organisations, en particulier les acteurs de petite et moyenne taille dans les secteurs de la production.

La dépendance multiple des industries vis-à-vis des produits chimiques fait de leur production l'un des secteurs industriels les plus mondialisés, générant un impact important sur la durabilité des chaînes d'approvisionnement. Le rôle économique essentiel des produits chimiques et leur contribution à l'amélioration du niveau de vie doivent être pondérés au regard de l'ensemble des coûts potentiels. Une analyse adéquate des coûts doit donc inclure *l'utilisation des ressources par l'industrie chimique*, comme l'eau et l'énergie, ainsi que les impacts négatifs potentiels des produits chimiques sur l'environnement et la santé humaine. Prendre en considération la gravité potentielle et la complexité de ces impacts, met en évidence le fait que la gestion rationnelle des produits chimiques est une question clé pour le développement durable [2].

En vertu de ce programme, le projet intitulé *Approches novatrices pour la gestion rationnelle des produits chimiques et des déchets chimiques* vise à fournir à trois groupes d'industries, à savoir, les producteurs de produits chimiques, les formulateurs et les utilisateurs industriels de produits chimiques, des approches novatrices et des solutions techniques spécifiques pour la gestion des produits chimiques et des déchets chimiques. L'objectif principal est de parvenir à une réduction de la consommation de produits chimiques tant dans leur production que leur application. D'autres objectifs portent également sur le remplacement des produits chimiques dangereux par des produits chimiques moins risqués, la réduction des déchets chimiques, la manipulation en toute sécurité des produits chimiques et la réduction des risques liés aux accidents avec des produits chimiques. Dans chacun des cinq pays participants (depuis 2013 : la Colombie, l'Égypte, le Salvador, le Maroc et le Pérou) et des trois groupes d'industries concernés par le projet, l'identification et la mise en œuvre d'alternatives et de solutions innovantes ont été faites pour les sous-secteurs industriels suivants : soit formulation de peinture, application de la peinture, finissage textile et polymères). Les évaluations des sous-secteurs dans chacun des pays participants ont mené à l'élaboration du présent *manuel technique*, qui vise à susciter des idées novatrices produisant des solutions innovantes et rentables ainsi qu'à permettre aux entreprises de ces pays et aux sous-secteurs de mettre en œuvre une gestion écologiquement rationnelle des produits chimiques et des déchets chimiques à fort impact.

2 General description of the paint & varnishes industry

2.1 Introduction

Paints are liquid, paste, or powder products which are applied to surfaces by various methods and equipment in layers of given thickness. The paints, coatings and varnishes industry consists of manufacturers of paints, inks, adhesives, and a variety of other specialty coatings that preserve, protect, and decorate products. "Coating" is a general term denoting a material that is applied to a surface. "Paint" indicates a pigmented material, while "varnish" refers to a clear lacquer.

Paints and varnishes must fulfil many requirements. They protect the substrate against corrosion, weathering, and mechanical damage; have a decorative function (automotive coatings, household appliances, furniture), provide information (traffic signs, information signs, advertising), or have other specific properties.

Because paint manufacturers range from very small operations producing only a few hundred tonnes of paint annually up to large companies producing several hundred thousand tonnes annually, a description of paint production processes cannot be really given. Large companies account for only about 20% of the worldwide market [3]. A further difficulty is the multiplicity of formulations: large paint factories must hold a range of up to 20,000 formulations to be able to serve their markets. In addition, national differences in environmental legislation make a uniform approach difficult.

2.2 Historical development

Paint made its earliest appearance about 30,000 years ago. Cave dwellers used crude paints to leave behind the graphic representations of their lives that even today decorate the walls of their ancient rock dwellings. The colors used were pure oil paints prepared from animal fat mixed with mineral pigments such as ochre, manganese ore (manganese dioxide), iron oxide, and chalk. The first painted objects come from China: furniture and utensils were covered with a layer of paint in an artistic design.

Natural products such as vegetable oils and wood resins remained the most important raw materials for paint production, until the Industrial Revolution. Besides mechanizing and professionalizing the paint industry, the Industrial Revolution also created vast new markets for paints, varnishes and coatings. Virtually every product created on an assembly line, from the Model T Ford to the latest-model television makes extensive use of paints and coatings to beautify, protect and extend the life of the manufactured goods.

In the 1920s, organic solvents have been introduced in paint industry. It was linked to the development of modern rapid-drying binders. Whereas the liquid components previously used in coatings were vegetable oils or water and possibly ethanol, it became necessary to use solvent mixtures to give accelerated drying and optimized paint-application properties.

Problems of environmental pollution also followed from the introduction of solvents. These were recognized by the late 1960s and became the subject of development work. Waterborne coatings, low-solvent coatings, solvent-free powder coatings, and new radiation-curing coating systems with reactive solvents that are bound chemically during the hardening process were developed. These environmentally friendly coating systems have gained a considerable market share. To sum up paints and coatings have evolved from the simple Early Man colors on cave walls into a primary protective barrier or an artistic design for our products [5].

2.3 Paint industry market

The major change that has taken place in the coatings industry during the last twenty years has been the adoption of new coating technologies. Until the early 1970s, most of the coatings were conventional low-solids, solvent-based formulations; waterborne (latex) paints, used in architectural applications, accounted for 30–35% of the total. In the late 1970s, however, impending government regulations on air pollution control focusing on industrial coating operations stimulated the development of low-solvent and solvent less coatings that could reduce the emission of volatile organic compounds (VOCs). Energy conservation and rising solvent costs were also contributing factors. These new coating technologies include waterborne (thermosetting emulsion, colloidal dispersion, water-soluble) coatings, high-solids coatings, two-component systems, powder coatings and radiation-curable coatings [4].

The following pie chart shows world production of paints and coatings:

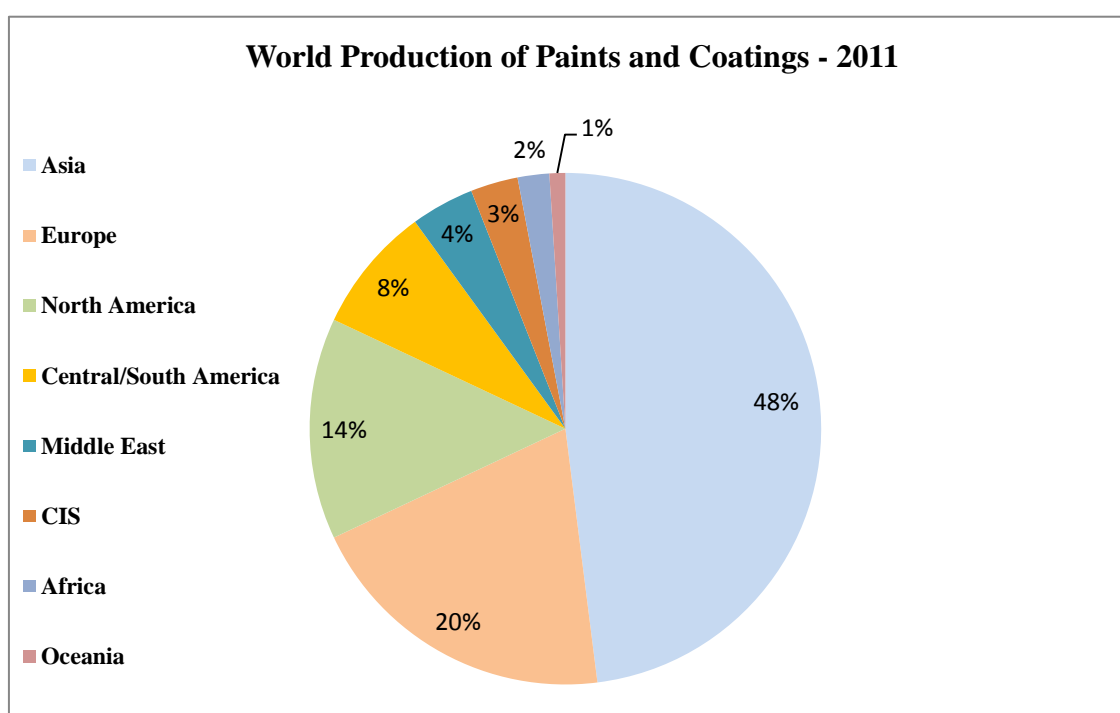


Figure 2-1: World Production of Paints and Coatings – 2011 [based on 4]

Paints and coatings industry in the United States, Western Europe and Japan is mature and generally correlates with the health of the economy, especially housing and construction and transportation. Overall demand from 2013 to 2016 will increase at average annual rates of 1–2% in the United States and 1.5–2.5% in Western Europe. In Japan, however, consumption of paints and coatings will experience relatively slow growth during this period (0.3%) as a result of no growth in major markets such as automotive OEM, machinery and appliances.

In the emergent countries of the world, coatings are growing at a much faster rate. The best prospects for growth are in Asia Pacific (8–10% growth per year in the near future), Eastern Europe (6%) and Latin America (6%).

Through the next five years, air pollution regulations will continue to be a driving force behind the adoption of new coating technologies. Despite the relatively slow growth in demand anticipated for coatings overall, waterborne and high-solids coatings, powders, UV curables and two-component systems appear to have good growth prospects [4].

2.4 Composition of paint and varnishes

The paint and varnishes industry typically uses a wide variety of materials depending on what type of coating/paint is being manufactured. Some common materials found include surfactants, chemical dryers, heavy metals (in the coloring and curing agents), epoxies, solvents, mild corrosives, polyurethanes, herbicides and fungicides. Some materials, such as the pigments and extenders, are in solid form but most of the materials encountered are in a liquid state. Paint components can also be classified as volatile or non-volatile. Volatile paint components include organic solvents, water, and coalescing agents. Non-volatile components include binders, resins, plasticizers, paint additives, dyes, pigments, and extenders.

The following figure resume paints components used and products of the paint industry.

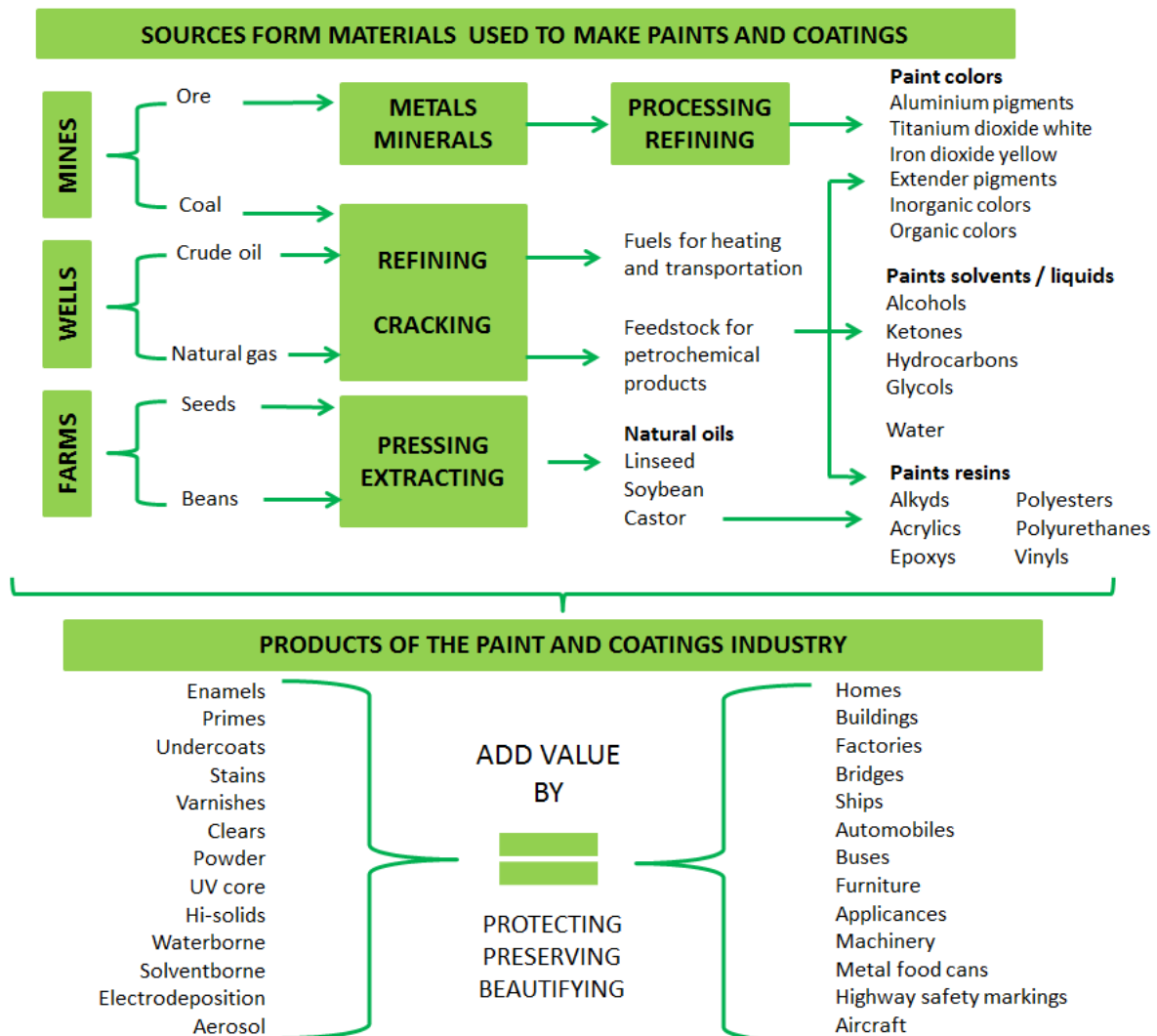


Figure 2-2: Paints components and products of paint industry [based on 5]

Products of the paint industry are generally obtained after the following four main stages:

- 1) Preparation of the millbase (premixing)
- 2) (Semi-)Continuous dispersion in perlmills or batch-dispersing in high speed stirrers (“dissolver”)
- 3) Completion of the formulation
- 4) Correction and adjustment of the final product

The following description briefly highlights the production of the industry's two main products: solvent-based paint and water-based paint. At a typical plant, both types of paint are produced [7].

The production of solvent-based paint begins by mixing some of these: resins, dry pigment, and pigment extenders, in a high speed mixer. During this operation, solvents and plasticizers are also added. Following the mixing operation, the batch frequently is transferred to a mill for additional grinding and mixing. The type of mill is dependent on the types of pigments being handled, so that no one style is universal. Next, the paint base or concentrate is transferred to an agitated tank where tints and thinner (usually a volatile naphtha or blend of solvents) and the balance of the resin are added. Upon reaching the proper consistency, the paint is filtered to remove solid residues and transferred to a loading hopper.

From the hopper, the paint is poured into cans, labelled, packed, and moved to storage. The water-based paint process is very similar to the solvent-based process. The major difference is the substitution of water for solvent and the sequencing of material additions. Preparation of water-based paint begins by mixing together water, ammonia, and a dispersant in a mixer. To this mixture, dry pigment and pigment extenders are added. After mixing, the material is ground in a mill and then transferred to an agitated mix tank.

Depending on the resin-system used, besides the resin itself plasticizers, other additives (e.g. antifoaming agent) are added and finally the viscosity is adjusted by adding of water.

Another very common option is to disperse the pigment and filler in the resin, grinding this mixture and add additives and water to the grinded mixture during the completion step like it is done for solvent borne paints.

Following this mixing operation, the handling of the paint is similar to that for solvent-based paints. At many facilities the grinding and the mixing and grinding operation may be bypassed with all the dispersion operations occurring in a single high-speed mixer.

3 Innovative solutions

3.1 Reduction of chemicals consumption

3.1.1 Chemicals used for paint-making

Paints and coatings are formulated products. All components fulfil special functions in the liquid paint and in the solid coating film. Solvents, binders, and pigments account for most of the material, the proportion of additives being small. Low concentrations of additives produce marked effects such as improved flow behavior, better wetting of the substrate or pigment, and catalytic acceleration of hardening. The most important component of a paint formulation is the binder. Binders essentially determine the application method, drying and hardening behavior, adhesion to the substrate, mechanical properties, chemical resistance, and resistance to weathering [3].

Binders and Resins

The base material, known as the binder, is the film-forming ingredient that largely determines the performance characteristics of the coating. In the past, binders were natural products such as linseed or soybean oils. Today, to achieve higher performance, almost all binders are synthetic polymers, [6] including high-volume resins such as alkyds, acrylics, vinyls, epoxies and urethanes, or lower-volume specialty resins such as polyesters, phenolics and silicones. The binder is compounded with fillers to extend the product, pigments to impart colour and solvents to control viscosity.

Plasticizers (see also paint additives)

Plasticizers are organic liquids of high viscosity and low volatility. The esters of dicarboxylic acids (e.g., dioctyl phthalate) are well-known examples. Plasticizers lower the softening and film-forming temperatures of the binders and also improve flow, flexibility, and adhesion properties. Chemically, plasticizers are largely inert and do not react with the binder components. Most binders used today are inherently flexible and can be regarded as "internally plasticized" resins. For this reason, use of plasticizers has declined.

Pigments and Extenders

Pigments and extenders in coatings are responsible for their color and covering power, and in some cases give the coating film improved anticorrosion properties. Pigments and extenders are finely ground crystalline solids that are dispersed in the paint. They are divided into inorganic, organic, organometallic, and metallic pigments. By far the most commonly used pigment is titanium dioxide. As a rule, mixtures of pigments are used for technical and economic reasons.

Paint Additives

Paint additives are auxiliary products that are added to coatings, usually in small amounts, to improve particular technical properties of the paints or coating films. Paint additives are named in accordance with their mode of action. Small quantities of a large number of other chemicals, such as thickeners, biocides, plasticizers, dispersants, defoamers, ultraviolet absorbers, driers, emulsifiers and adhesion promoters, are added as required in each formulation

Solvents

Solvents are compounds that are liquid at room temperature (and atmospheric pressure). Those most commonly used in coatings technology are aromatic and aliphatic hydrocarbons, esters of acetic acid, glycol ethers, alcohols, and some ketones. Solvents dissolve solid and highly viscous binder components. Organic solvents are used in most liquid coatings systems, including waterborne coatings, in which they perform important functions.

3.1.2 Process technologies to reduce chemical consumption

Several techniques are appropriate for the recovery of solvent from a solvent-laden air stream. It depends on a number of factors. The following table is intended to be a quick reference guide to the criteria used to select a particular solvent recovery system.

Table 3-1: Solvent recovery techniques

Technology	Flow rates (m ³ /hr)	Solvent concentration (mg/m ³)
Adsorption/desorption	100-500,000	500-10,000
Adsorption capture systems	10-1,000	10-10,000
Coolant/refrigerant condensation	100-50,000	5,000-100,000
Cryogenic condensation	10-5,000	5,000-50,000
Absorption (scrubbing)	100-20,000	500-10,000

Increase of solvent recovery by using a distillation unit

This example comes from Wattyl Australia (manufacture of solvent-based paints for the industrial and automotive refinish markets) [8] which took just one year to recoup a \$100,000 investment in a

distillation unit that recovers solvent used in cleaning tanks and equipment in plants manufacturing solvent-based paints.

Cleaner production initiative

Participation in the Cleaner Technology Incentive Scheme sponsored by the Victorian EPA has resulted in the purchase of a small distillation unit capable of handling 800-900 litres/day of dirty solvent. A process group, comprising representatives from management, technical and factory staff, was set up. Over a period of 3-4 months, the group introduced a series of formalised cleaning procedures: random choice of cleaning solvent was replaced by an evaluation process, leading to a choice of one single solvent for all tank and equipment cleaning, manufacturing procedures were modified to minimise or eliminate the use of wash solvent and waste streams were separated and segregated, and a process of formal identification and recording introduced to provide traceability.

The distilled solvent was, in most cases, about 90% pure. Initially, it was intended to use the distilled solvent as wash solvent, but even 10% dilution significantly reduced cleaning efficiency. It was trialled as a partial replacement for purchased solvent in several blended thinner formulations which Watty found to be satisfactory in many of the products. By using the distilled solvent to replace new solvent, it was easily converted to a relatively cheap, gun-wash washing solvent that can be sold.

Advantages of the process

Watty once had to dispose of 130,000 litres of dirty solvent wash and considerable quantities of waste paint each year.

It is now able to:

- distil 800-900 litres/day;
- recover up to 90% of wash solvent, which is re-used into finished product and gun-wash washing solvent;
- recover the distillation sludge as a raw material in a specially formulated paint product; and recover about 60% of waste paint, which was previously disposed off-site, and use it to produce the same paint product. Thus, this process can also be used for the reduction of chemical waste.

The \$100,000 capital investment in the distillation unit was re-couped in just over 12 months of operation.

Decrease solvent loading by using condensation and associated techniques

Condensation systems have traditionally been considered useful preliminary recovery units to reduce a high solvent loading prior to further recovery, for example using an activated carbon adsorption bed. While this remains a feasible arrangement, developments in both heat exchanger systems and use of low temperature fluids mean that condensation systems are now a viable stand-alone option for solvent recovery.

While conventional condensation techniques are most suitable for solvents with a reasonably high vapour pressure, cryogenic condensation is able to cope with all solvents irrespective of their vapour pressures [9].

General principles

In practice, there are technical and economic limits to the application of condensation to solvent recovery. If the concentration of the solvent vapour is very low, the temperature may need to be lowered significantly before condensation commences. This may require temperatures that are difficult to attain.

Technical considerations

Although condensation systems can recover almost any solvent, the feasibility of condensation as a recovery technique depends on the condensing temperature required. Generally, the lower the boiling point of the solvent, the more difficult it is to recover. Cryogenic condensation is an option if

condensing temperatures lower than -30°C are required. Solvent mixture recovery by condensation is simple, being limited only by the condensation temperature. Coolant/refrigerant condensation is a proven technology with thousands of applications worldwide. Cryogenic systems are less widespread, with fewer than 100 end-of-pipe systems worldwide.

Besides the technical problems and the high energy consumption of Cryogenic condensation the parallel condensation of humidity from the air leads to mixtures with a reasonable water content, which reduces the usage of the condensed solvent if the solvent is (even particularly) mixable with water.

Condensation filtration recovery systems

This specialised condensation system uses surface condensation and microfiltration to recover solvents. It is particularly suited to the heat-set web offset printing sector. A typical system consists of three main elements:

- a condensation unit;
- a moving bed filter;
- a mist eliminator.

In a typical system, see Figure 3-1, an air stream at $160 - 180^{\circ}\text{C}$ enters the condensation unit where it is cooled to 40°C using ambient air. The high boiling point solvents condense, forming a liquid condensate and a mist of liquid solvent droplets. The condensate passes to a liquid solvent filtration unit where any solid contaminants are removed - and into a solvent/water separator.

Approximately 60% of the liquid component is removed in the condensation stage. The recovered solvent is passed to the main solvent storage tank for re-use.

Combined condensation and filtration systems are ideally suited for the recovery of high boiling point solvents.

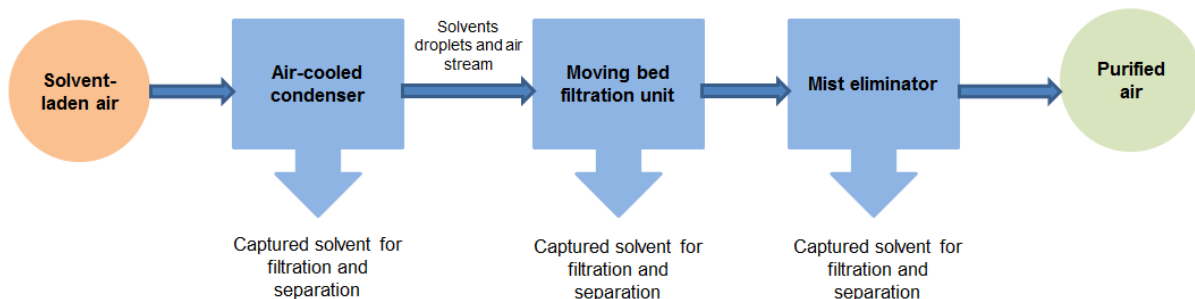


Figure 3-1: Typical condensation filtration recovery system [based on 9]

Cryogenic condensation

Condensation at extremely low temperatures can be carried out using cryogenic nitrogen. Nitrogen has the following properties that make it ideal for use as a low temperature refrigerant:

- low boiling point (-196°C);
- non-toxic;
- non-corrosive;
- non-flammable.

Figure 3-2 shows a simplified plant design where liquid nitrogen is vaporised in the recovery unit. The vaporised nitrogen gas is used to blanket several processes before returning to the recovery unit carrying solvent vapours from the processes. The solvent is condensed and separated by the recovery unit, while the purified nitrogen gas is vented to the atmosphere. [9]

- electricity for fans and refrigerant plant.

An estimated 10 kg/h of nitrogen cooling in the condensers is needed for each kilowatt of cooling required, but this depends on plant design, solvent type, etc. A typical inert gas cycle plant may use 1-2 tonnes/day.

Cost factors

The following factors influence the cost of a condensation recovery system.

- *Emission flow rate.* This influences the overall size of the system.
- *Temperature reduction required.* The greater the reduction in temperature to achieve the required levels of solvent recovery, the more expensive the equipment. This is especially true for condensation temperatures well below 0°C because of the greater heat exchange surface required and the need for specialist equipment for low temperature operation.
- *Solvent mixtures.* Multi-component solvent streams are likely to require more complex separation techniques.
- *Solvent solubility.* The more soluble the solvent is in water, or other components present in the stream, the more complex the separation technique likely to be required.

Operating costs

The following factors influence operating costs.

- *Emission flow rate.* This dictates utility requirements.
- *Cooling load.* The greater the required cooling load, the more expensive the supply of cooling agent. This is especially true for condensation temperatures well below 0°C, as cryogenic systems can incur much higher costs unless nitrogen is already used on-site.
- *Solvent mixtures.* More energy-intensive separation techniques are likely to be required.
- *Solvent solubility.* The more soluble the solvent is in water, or other components present in the stream, the more energy-intensive the separation technique likely to be required.

Uses and limitations

Coolant and refrigerant condensation are proven technologies. Although widely used, it is traditionally been used for preliminary recovery prior to, for example, adsorption.

The economic feasibility of condensation depends on the temperature reduction required for effective recovery. Condensation temperatures well below 0°C can involve higher capital and operating costs unless nitrogen is already used on-site. Concerning cryogenic systems, they are more likely to be economic where nitrogen is already used on-site.

To reduce operating costs, changing from air to inert gas allows the airflow rate to be decreased and solvent concentrations increased (without compromising safety). Furthermore the often disturbing condensate of water (from ambient air) is not relevant. Thus, it makes solvent capture and re-use more cost effective.

3.1.3 Possible suppliers

A table with possible suppliers of solvent distillation equipment is available in Appendix 1. It was issued by Minnesota Technical Assistance Program [12]. In Appendix 2 suppliers for high pressure wash systems are listed [11], in Appendix 3 suppliers for adsorption process and solvent recovery [13], [14], [15].

3.2 Substitution of hazardous chemicals

3.2.1 Hazardous chemicals used

Paint manufacturing activities may include the use of hazardous chemicals in process to provide the final product with desired visual and functional properties. Main pollutants in the liquid effluents from paint industry are:

- Metals in the pigments
- Organic Solvents
- Organic compounds (present in resins, additives, organic pigments and raw materials)
- Other pollutants (silica, carbonates, sulphates etc.)
- Oils present in resins
- Suspended solid materials

Main hazard in paint industry is related to the evaporation of solvents of VOCs which are dangerous for both health (toxicity) and environment (pollutants). Releases of volatile organic compounds from paint and ink manufacturing include those from the process steps and from clean-up operations. However, very little information is available which quantifies these emissions: Many paint and ink manufacturing facilities calculate total plant VOC emissions based on raw material consumption rather than calculating emissions from processes or equipment by an alternative method. Emission values therefore reflect solvent losses from manufacturing, cleaning, and storage. Because emissions have not been quantified, there are no publicly available data about emission factors for paint and ink manufacturing processes.

To protect operating personnel from the toxic effects of evaporating solvents, safety measures such as ventilation and air exhaust are necessary. To protect the environment, incineration and sometimes a solvent-recovery plant is installed to prevent solvents entering the atmosphere.

Other measures for the protection of the workplace and the environment from solvent vapors include the development and use of new low-solvent or solvent-free coatings. This chapter mainly focuses on substitution of hazardous solvents.

3.2.2 Solvent selection method

Solvent selection is a key part of process development. Because of the volumes used, solvents can often result in the biggest environmental, health and safety impact of a process. There are a number of methodologies to aid in the search for environmentally benign solvent systems. Table 3-2 and

Table 3-3 show an example for a solvent selection guide [10]. Each table assigns a score from 1 to 10 for each solvent under the respective categories with 10 being of concern and 1 suggesting few issues. The table is further simplified by using colour coding with scores between 1 and 3 being green, 4 to 7 yellow and 8 to 10 red. Categories are further explained Table 3-4.

Table 3-2: Solvent selection table part 1 [based on 10]

Substance		Safety		Health	Environment						
	Name	CAS N°	Flammability	Static	Health	Impact on air	VOC potential	Impact in water	Potential biotreatment plant load	Recycle	Incineration
Acids	Methane sulphonic acid ¹	75-75-2	1	1	1	1	1	7	4	6	8
	Propionic acid	79-09-4	3	1	4	7	1	1	5	6	6
	Acetic acid (glacial)	64-19-7	3	1	8	6	3	1	5	6	6
	Formic acid	64-18-6	3	1	10	4	5	1	5	6	7
Alcohols	Isoamyl alcohol	123-51-3	3	1	2	1	1	2	4	5	3
	1-Pentanol	71-41-0	7	1	1	2	1	1	4	5	3
	Isobutanol	78-83-1	7	1	3	2	2	1	5	7	3
	n-Butanol	71-36-3	7	1	4	3	2	1	5	6	3
	Isopropanol	67-63-0	7	1	3	1	5	1	6	5	5
	IMS/Ethanol	64-17-5	7	1	2	2	5	1	7	5	5
	Methanol	67-56-1	7	1	5	3	6	1	7	4	5
	t-Butanol	75-65-0	7	1	6	2	4	3	7	5	5
2-Methoxy ethanol ²	109-86-4	3	1	10	8	2	2	5	6	5	
Alkanes	Isopar G	90622-57-4	3	10	1	1	1	10	3	10	1
	n-Heptane	142-82-5	7	10	3	1	5	8	5	2	1
	Isooctane	540-84-1	7	10	3	1	5	10	5	2	1
	Cyclohexane	110-82-7	7	10	6	1	6	9	5	2	1
	Solvent 30 (assumed benzene free)	64742-49-0	7	10	2	1	4	10	4	10	1
	Isohexane	107-83-5	7	10	6	1	8	10	6	1	1
Aromatics	Xylene	1330-20-7	7	10	2	4	2	7	3	4	1
	Toluene	108-88-3	7	10	5	2	4	7	4	4	1
Basics	Triethylamine	121-44-8	7	1	10	6	6	5	6	5	4
	Pyridine	110-86-1	7	1	9	10	3	4	7	6	6
Chlorinated	Chlorobenzene	108-90-7	7	1	6	4	2	9	2	4	5
	Methylene chloride ³	75-09-2	1	1	9	9	10	6	5	2	8

Table 3-3: Solvent selection table part 2 [based on 10]

Substance		Safety		Health	Environment						
	Name	CAS N°	Flammability	Static	Health	Impact on air	VOC potential	Impact in water	Potential biotreatment plant load	Recycle	Incineration
Esters	n-Butyl acetate	123-86-4	7	1	2	3	2	3	3	4	3
	Isopropyl acetate	108-21-4	7	1	4	2	5	2	5	4	3
	Ethyl acetate	141-78-6	7	1	5	2	6	2	5	5	4
Ethers	Diphenyl ether	101-84-8	1	1	1	4	1	8	3	4	2
	Anisole	100-66-3	3	10	2	1	1	4	3	6	2
	Tetrahydrofuran	109-99-9	7	1	8	1	7	3	7	6	5
	Diglyme	111-96-6	3	1	10	7	1	5	5	10	5
	1,2 Dimethoxyethane	110-71-4	3	1	10	3	6	5	7	8	5
	MTBE	1634-04-4	7	1	9	2	8	7	7	5	3
	1,4-Dioxane	123-91-1	7	10	9	3	4	4	6	9	5
	Diethyl ether	60-29-7	10	10	7	3	10	4	7	6	3
Fluorinated	Trifluorotoluene	98-08-8	7	10	4	6	5	8	3	4	6
Ketones	MIBK	108-10-1	7	1	6	1	3	2	4	7	3
	Methylethyl ketone	78-93-3	7	1	7	4	6	1	6	7	4
	Acetone	67-64-1	7	1	6	3	8	1	8	4	5
Polar aprotic	DMSO ⁴	67-66-5	1	1	1	1	1	3	5	6	6
	N-Methyl pyrrolidone	872-50-4	1	1	1	1	1	1	6	6	6
	Sulfolane	126-33-0	1	1	1	3	1	4	5	6	7
	Dimethyl acetamide	127-19-5	3	1	4	7	1	2	6	6	6
	DMF	68-12-2	3	1	9	7	1	1	5	6	6
	Acetonitrile	75-05-8	7	1	8	2	6	4	8	5	6

¹ The "impact in water" score for methane sulphonic acid has been based on limited data.

² 2-methoxy ethanol is on the Swedish Restricted Chemicals List. The comment is that "the goal is to phase out this substance". Therefore, use in Sweden will need careful consideration.

³ In Sweden, methylene chloride is essentially banned for use in processes.

⁴ DMSO can decompose to form dimethyl sulphide. This is an extremely dangerous substance and requires high levels of abatement to prevent odour being an issue. Also under the UK regulations, organic sulphides have a benchmark release of 2 mg/m³. Care should be taken to assess emission levels of dimethyl sulphide when using DMSO.

Table 3-4: Solvent selection method [based on 10]

Safety	Flammability	Assessed according to the UK National Fire Protection Association's (NFPA) scoring system.
	Static	A score of either 1 or 10, depending on whether the material can accumulate an electrostatic charge. (It is important to note that electrical resistivity will depend on the source, purity, potential contaminants and any other material dissolved in the solvent. Care is needed when applying such data. If there is any doubt, a sample should be tested.)
Health		Rating is primarily based on the exposure potential. This is estimated by calculating the vapour hazard rating: saturated concentration at 20 °C divided by the Occupational Exposure Limit (OEL).
Environment	Impact in air	The category is made up of five separate elements. These are the UK Long Term Environmental Assessment Level (EAL), VOC Directive impact, rate of photolysis, Photochemical Ozone Creation Potential (POCP) and odour potential.
	VOC potential	Assesses the magnitude of likely emissions based on the vapour pressure of the solvent at 20 °C.
	Impact in water	Judged on the criteria of toxicity, biodegradability and the likelihood of bioaccumulation (as estimated from octanol/water partition coefficient). If the process is unlikely to contain any streams suitable for ultimate release to water, this category could be ignored. However, the category is still relevant for accidental releases from the processes.
	Potential biotreatment plant load	Estimates the effect of a solvent on the operation of a biological treatment facility. It assesses impact due to load (both carbon and nitrogen loading), the effects of air stripping from the plant and, in the instances of processes where water is present, the increased effect of solvents due to their water solubility. If the process is unlikely to contain any streams suitable for biotreatment, this category could be ignored.
	Recycle	Assesses the potential ease of recovery of the solvent. The elements that are used to assess this are the number of other solvents in the guide with a boiling point within 10 °C, the boiling point, the risk of peroxide formation on distillation and the water solubility (affecting potential loss in aqueous streams).
	Incineration	Key properties of solvents for incineration are heat of combustion, aqueous solubility, and halogen, nitrogen and sulphur content. Some of these problems can be minimised by blending with other waste solvents by the incinerator operator. However, this has not been taken into account in the scoring system.

1 The safety considerations in the guide are limited to operational hazards, i.e. fire and explosion hazards.

2 Many of the subcategories in this section assume that the solvents are used in an aqueous process. It is important to use judgement when applying the scores to solvent only processes.

Also in absence of a comparative analysis of the adopted techniques aimed to identify and to propose formal BATs, tables presented before, are a good starting point to improve the use of hazardous chemical products. However, the final categorization of the substances needs to correlate with Globally Harmonized System (GHS) classification.

3.2.3 Lead-free paints

‘Lead paint’ refers to a product which is produced using specific lead compounds to give paint its colour, to allow the paint to reduce corrosion on metal surfaces, or to help the paint dry more quickly. Lead compounds may also be present in a range of coatings such as varnishes, lacquers, stains, enamels, glazes or primers [16].

Lead can also be found as a contaminant in other raw materials that are used to make paint and other products, and as a result manufacturers must closely monitor overall lead content. Efforts should be made to keep the total lead content in paints as low as possible.

Since the first part of the 21st century, restrictions on the use of lead in paints have been enacted in a number of countries. Despite these efforts, it has become clear in recent years that paints containing high levels of lead are still widely available and used in many countries for decorating the interiors and exteriors of homes. It can also be found in paint in public buildings such as schools and hospitals, as well as on toys, toy jewellery, glazes, furniture, and playground equipment.

Exposure to lead and health effects

Exposure to lead from paint can occur during manufacture and application. One of the most common and most concentrated sources of lead exposure for children is lead paint and paint dust. Exposures can continue for many years as the paint deteriorates or is removed during painting and demolition.

Lead is a highly toxic metal found in small amounts in the earth’s crust. Because of its abundance, low cost, and physical properties, lead and lead compounds have been used in a wide variety of products including paint, ceramics, pipes, gasoline, batteries, and cosmetics.

Lead is taken up by humans by ingestion and inhalation. Eating lead bearing paints by children and drinking of lead contaminated water are important sources of non-industrial poisoning [17]. Lead absorbed in course of occupational exposure is superimposed on lead absorbed from other means which leads to increased body burden of lead.

Exposure to lead can cause a variety of neurological disorders such as lack of muscular coordination, convulsions and coma. Lower levels of lead have been associated with measurable changes in children’s mental development and behaviour [18]. These include hyperactivity; deficits in fine motor function, hand-eye coordination, and reaction time; and lowered performance on intelligence tests. Chronic lead exposure in adults can result in increased blood pressure, decreased fertility, cataracts, nerve disorders, muscle and joint pain, and memory or concentration problems.

The effects of lead toxicity have been well established, with clear evidence of harm found in children whose blood lead levels are above 10 µg/dl and some evidence that harm may occur at lower levels [17].

A common source of lead exposure for children today is lead based paint and the contaminated dust and soil it generates [17].

According to an Indian study more than 60% of enamel paints contained lead higher than 5,000 ppm and the maximum content of 140,000 ppm was found in yellow enamel paint [19].

Ambient air concentration of lead during the operation of paint mixing, paint spraying (chrome yellow) may be at an average of 1.75 mg/m³ and 3.9 mg/m³ respectively [19].

Poisoning from lead-based paint has affected millions of children since this problem was first recognized more than 100 years ago [17]. Some of the developed countries have established limits on the lead content of paint e.g. US regulation of the lead content in new paints is 600 ppm. In many

countries however there are apparently still no regulations on lead content of either new paint or paints in houses.

The following table sum up effects to exposure of lead paints [20].

Table 3-5: Main routes of lead exposure and critical effects identified with associated B-Pb levels for various population groups [based on 20]

Routes of Intake	Population Group	Effects	Critical B-Pb Level (µg/l)
Placenta	Foetuses	- Delays in neurological development	Probably no threshold
Mother's milk, inhaled air	Neonates and young children	- Inhibition of d-aminolevulinic acid dehydratase (ALAD) - Physical development	30-300 <70
Inhaled air, hand-mouth behaviour, ingestion	Children	- Decreased nerve conduction velocity - Cognitive development and intellectual performance - Hearing loss - Jaundice - Anaemia	200-300 <100 <100 350 >200
Inhaled air, food ingestion	Adults	- Decreased ALAD activity - Blood pressure - Damage to renal function - Sperm count	30-340 <20 20-100 400-500

Possible substitute

Good substitutes for lead in paint have been known for many years. Paints without lead are available which are similar in performance to lead paints.

Paint manufacturers replaced white lead with a less toxic substitute, titanium white (based on the pigment titanium dioxide) which was first used in paints in the 19th century. It is considered safe enough to be used as a food coloring and in toothpaste, and is a common ingredient in sunscreen. The titanium white used in most paints today is often coated with silicon or aluminium oxides for better durability.

When they invent new paints, it is imperative for engineers to achieve functionality of anticorrosion and opacity as high as lead-based paint. Acceptable products are already available for vehicles, electronics, furniture, ornaments and anti-fouling paint for ship bottom [21].

An approach to manage the challenge of eliminating lead in paint is to strengthen technical assistance for industries [21] to help them to eliminate lead paint step by step from their production processes and push for collaboration between industry and governments to come up with guidelines on suitable substitutes for the lead compounds used in paint manufacturing.

As explained below, metallic dryers accelerate the drying of paints, coatings and inks by catalyzing the oxidation of drying oils and synthetic resin varnishes. The following chemicals may be used as lead substitute: [22]

Manganese: This promotes both superficial as well as complete drying, although it is less efficient in air-dried paints. It is recommended for use in baking finishes.

Calcium: An auxiliary drier that is most commonly used in paints and in combinations with zirconium, serves as a lead substitute. It also can be used as a wetting agent in the pigment grind.

Zinc: As an auxiliary drier it has the advantage of keeping the film surface “open” during drying and allowing air to reach the lower layers.

Zirconium: Another important auxiliary drier functioning as a catalyst of cobalt and manganese driers. It has also proven to be the most useful auxiliary drier as a replacement for lead in fume-proof paints and other situations where a lead-free system is desired. It shows improved gloss and color retention as compared to lead but does not perform as well as lead under adverse drying conditions of low temperature and high humidity.

Bismuth: The newest alternative as a lead substitute that is used in traditional combinations with cobalt and manganese.

Lithium: Generally employed together with cobalt and calcium to substitute lead in high solid systems.

Barium: Used to improve the hard-dry probabilities, often used in combinations with Co and Zr.

In general in many cases combinations of different metals (mix-dryers) are sold and used.

3.3 Reduction of chemical waste

3.3.1 Waste generated by paint & varnishes industry

In the paint and varnishes production there are in general several potential sources of waste, caused by following departments of a typical company:

Sales

- Number of products: Sales departments tend to try to fulfil any requirement of their customers, causing a wide variety of raw materials and complex production planning with lots of cleaning
- Logistic of production: delivery times are often underestimated by Sales leading to a change of production plans (cleaning!)
- Volume of stock is too high, to be able to deliver fast leading to potential increase of products with expired shelf life

Production

- Bad housekeeping and/or maintenance leading to dirty cans, leakage
- Inefficient production equipment (pre-dispersing, dispersing, blending, filtration)
- Batch size: Small batch sizes create more waste than bigger ones
- Logistic of production: producing sequences of similar products should be at least one of the aspects of production planning

QC-Laboratory

- Samples

R&D Laboratory

- Sample batches
 - Unstable formulations which cause off-spec products in case of small deviations (e.g. temperature, dispersing parameters, impurities of raw materials)
-

- Usage of an unnecessary number of new raw materials instead of testing existing ones

Warehouse raw materials & products

- Outdoor storing of raw materials and/or cans leading to rusty cans, wet solids, overheated liquids
- Mechanical damage of drums, bags etc.
- Wrong storage organisation (e.g. FINO – first in never out)
- Stock volume too high: possibly exceeding shelf life of raw material
- Dirty conditions: Final products have to be repacked before selling

Purchasing

- Buying too high quantities of raw materials at a “better” price
- Defining too low minimum stocks for often needed materials and troubling production planning
- Accepting/Ignoring of impurities (type and/or share) potentially causing off-spec products

General Management

- No real interest in environmental matters like waste
- Defining revenue as the most relevant factor, leading to sales orientated policy
- Restricted investment policy preventing improvements

Analysing the total volume of waste per year regarding the source might be a useful first step to identify sufficient measures to reduce the waste volume.

Environmental as well as health and safety considerations are motivating much of the ongoing technological development in the paint and varnishes industry. For example, paints and coatings have been identified as significant sources of volatile organic compounds (VOCs). In combination with nitrogen oxides, VOCs are responsible for the build-up of ground-level ozone. This ozone causes respiratory problems, vegetation damage and material degradation [10]. During the vat cleanings, waste products were often washed into a sewer drain. Common waste products encountered include:

- paint,
- volatile organic compounds,
- waste metals (from the pigments),
- waste or spent polymers, surfactants,
- herbicides,
- anti-bacterial agents,
- mild corrosives (for cleaning the process line and vats).

Most of these compounds are in the form of sludges and/or solids and will harden over time if not utilized. These materials may be in drums, tanks or in the process lines themselves.

There has been a significant shift during the past 20 years in the use of formulations based on petroleum solvents to formulations based on water as the primary solvent. In addition to reducing VOC emissions, water-based formulations offer advantages such as fewer odours. However, there are still applications where the necessary performance can be achieved only by using solvent-based systems.

3.3.2 Process technologies to decrease waste generation

Materials Management and Housekeeping

According to a study written by Washington State Department of Ecology, housekeeping is an important factor in reducing wastes. There was wide variability in how successful the different

facilities were at maintaining an organized operation. The facilities with a focus on housekeeping and tracking were more organized and efficient in managing their materials. Housekeeping is how the materials are handled, stored, and maintained at a facility, and is one of the easiest and least expensive ways to reduce waste, increase efficiency, and reduce liability.

Some examples of good housekeeping are:

- Labelling and dating all containers.
- A management policy and actions that maintain a well-organized facility.
- Uniformity of practices (for formulating-blending, clean-up, etc.).
- Training for all employees on the established practices and protocols of materials management, including storage, clean-up, and handling of materials.
- Good communication between workers.
- Routinely inspecting/checking the facility.
- Documenting plant operations with flow diagrams and process specifications.
- Establishing simple names/codes for materials.

Other measures which could be applied in paint & varnishes industry are as follow:

Materials Tracking

Paint and coating manufacturing involves materials-intensive batch production processes. The ability to accurately and efficiently track and manage raw materials inventories is a key to successful production management. For example, environmental software including hazardous material management may be used.

High-Pressure Wash Systems

A potential future opportunity is to use pressurized water to clean tanks. The pressure affords mechanical energy that removes coating product from the tank wall thus reducing the quantity of liquid required and waste liquid generated. Possible suppliers of High Pressure wash systems are listed in Appendix 2: Suppliers for high pressure wash systems.

Wash Water Recirculation/Filtration

The concept here is to filter or centrifuge wash water for continued re-use. Rinsing tanks that have been used to formulate water-borne products, and to rinse raw material totes and containers generate wash water. Though many facilities are able to successfully reincorporate the rinse/wash water into subsequent formulations, sometimes the rate of wash water generation exceeds the rate at which wash water can be reworked. A closed-loop, recirculating, pressurized wash water system could significantly reduce cleaning water generation and reduce water discharge or need to re-work wash water. Pressurized water is sprayed through a nozzle, used to rinse the container, and the rinsate is collected in a reservoir. The rinsate is filtered and transferred to the feed tank and is used again. Possible suppliers of this technology are listed in Appendix 2: Suppliers for high pressure wash systems.

Counter-Current Rinsing

Counter-current rinsing is the process of matching a rinse solution to the rinse job, based on the initial level of contamination in the solution. In other words, using “dirty” (but not spent) solvent for first rinse, followed by a slightly cleaner solution for the second rinse, ending with final rinse of clean or virgin solvent. This method significantly reduces the volume of solvent or water needed for cleaning, and is particularly effective with at least three stages.

Testing Raw Materials

This simple practice prevents off-spec material from ruining product batches.

Increased dedication of Filling Units

Increased dedication of filling units is a potential opportunity for several facilities. Dedicating equipment to a particular product or line of products reduces the need for cleaning solvent (clean less frequently and thoroughly).

Automated Tank Cleaner

This is a viable future opportunity, particularly when employee health impacts from manual tank cleaning are considered. This practice could be particularly effective if pressurized wash fluid (solvent or water) is used, thereby reducing the amount of fluid needed per tank cleaning.

Employee Incentives

A non-technical measure and a future reduction opportunity could be to provide bonuses, rewards, or incentives for employees who reduce wastes. This has a low implementation cost, but could result in significant reductions and encourage teamwork.

Solvent recovery technique

Solvent recovery by adsorption is a proven technology, which has been used since the 1930s, and is still extensively used. It is suitable for use in applications where:

- solvents are readily adsorbed onto activated carbon or other adsorbents;
- contaminant and humidity levels in the air stream are low.

Solvent compatibility

While a wide range of solvents can be removed by adsorption (see Figure 3-3), not all are recoverable by desorption. Desorption of high boiling point solvents (higher than 200°C) requires more energy. Phenols and nitriles are particularly difficult to desorb. Cyclohexanone is prone to polymerise when adsorbed, significantly reducing adsorbent life and creating a potential flammability hazard.

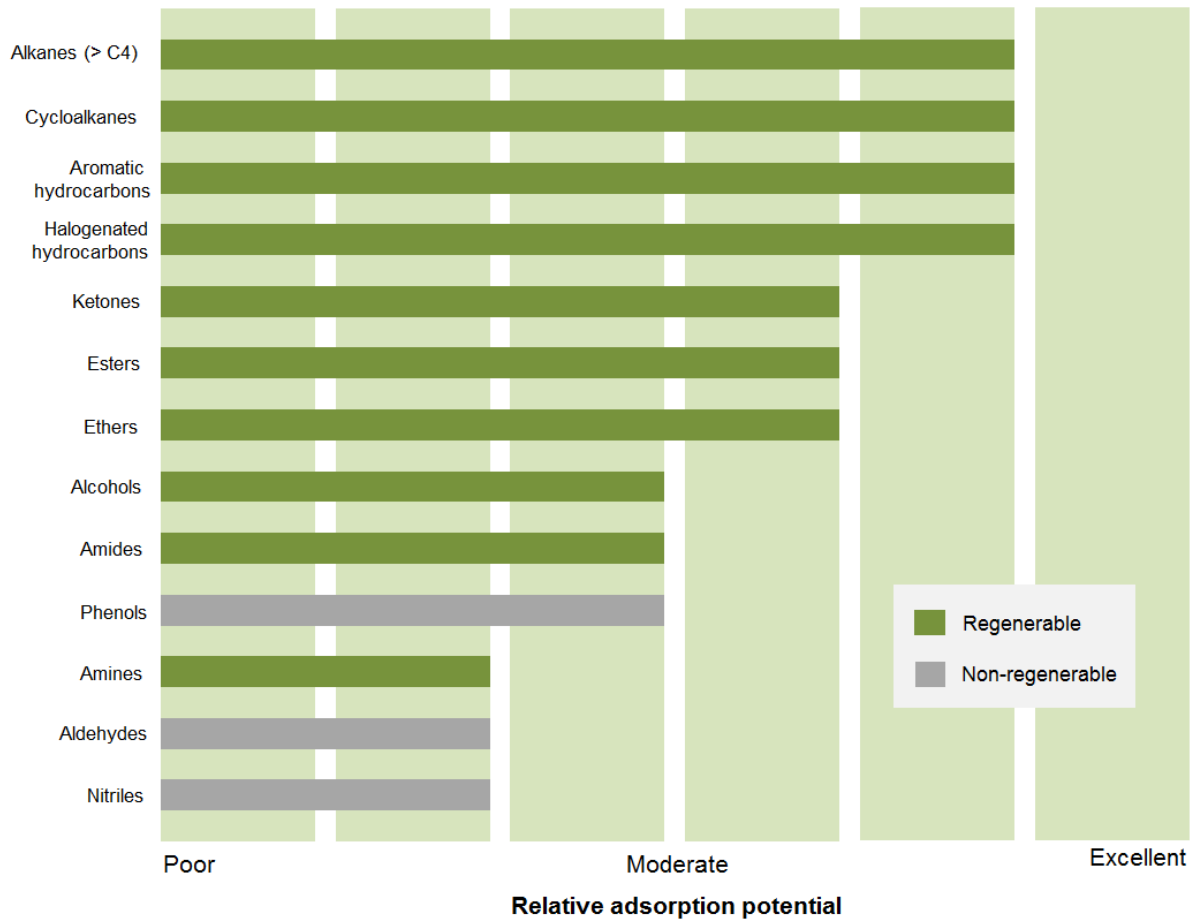


Figure 3-3: Adsorption potential of granular activated carbon (GAC) with various organic solvents [based on 9]

Hydrolysis of normally stable solvents can occur when the solvent is adsorbed on a GAC surface. In the case of chlorinated solvents, the resulting hydrochloric acid can lead to corrosion problems. Ketones and aldehydes have a tendency to oxidise in the presence of GAC, producing carboxylic acids and liberating substantial amounts of heat. Failure to control these reactions and to cool the GAC adequately can result in a chain reaction leading ultimately to oxidation of the GAC matrix and auto-ignition of the GAC. The latter occurs at around 370°C.

Low volatility solvents are more readily adsorbed than solvents with a high volatility. They therefore will tend to displace the more volatile ones as the bed becomes more saturated. This problem can be overcome by careful design, for example:

- Providing sufficient adsorption capacity for the mixture.
- Using adsorption beds in series.

The following table shows the typical adsorption efficiencies for six common solvents using GAC as the adsorbent.

Table 3-6: Effect of varying feed concentrations on mass of solvent absorbed

Solvent	Adsorption efficiency (%)		
	1 g/m ³ feed	10 g/m ³ feed	100 g/m ³ feed
Dichloromethane	11	31	45
Styrene	34	38	41
Tetrachloroethylene	50	61	65
Toluene	32	34	37
1,1,1-Trichloroethylene	33	47	55
1,1,2-Trichlorotrifluoroethane	11	29	45

The operating costs of adsorption capture units consist mainly of the cost of supplying and regenerating the GAC. The frequency of re-supply depends on the capacity of the unit and the solvent loading, while the airflow dictates the size of the unit. Such systems are likely to be most cost-effective for low concentration streams (up to a few hundred ppm) or infrequent emissions.

The previous figure and table may be used to determine the relevance to apply adsorption technology depending on solvent used, i.e. the type of paint which is formulated

Example of adsorption technique fixed bed process

This process variant involves the alternate batch-wise adsorption and desorption of the solvent in a fixed bed of adsorbent. More than one adsorber is required for continuous operation. Twin beds are typical, with one bed adsorbing the solvent while the other is being regenerated. Third or fourth beds may be required if: the time required for the adsorption phase differs from that for the desorption phase; stand-by capacity is required.

A typical twin-bed adsorption process is shown in the following figure:

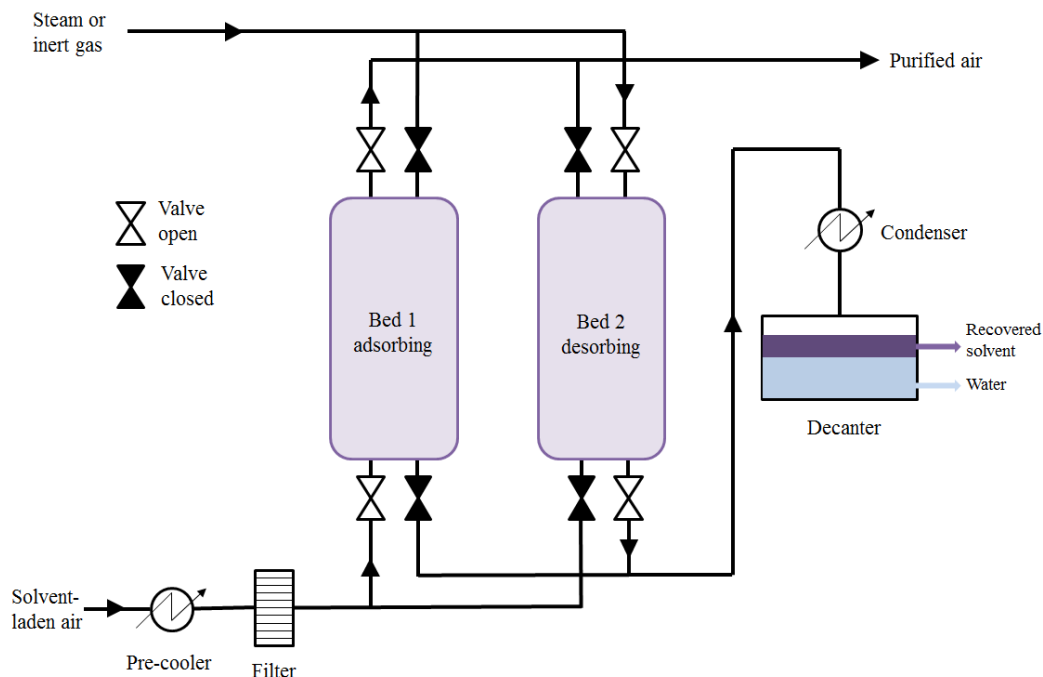


Figure 3-4: Typical twin-bed adsorption process [based on 9]

In the figure above, solvent-laden air flows upwards through the adsorbing bed, venting to atmosphere from the top or side of the adsorber shell. When breakthrough is achieved, the adsorber is switched to desorption, steam or inert gas passing downwards through the desorbing bed.

Adsorption cycles are controlled by one of the following:

- a gas analyser using a set solvent breakthrough concentration to switch adsorbers;
- a calculated fixed time cycle.

Example technique: plasticiser/solvent recovery system

Existing technology for the removal of plasticiser and solvent fumes from exhaust gases is being developed to enable recovery of both plasticiser and solvent. In the initial stage, the exhaust gas is cooled to below 15°C to maximise the amount of solvent in the liquid phase. This is followed by an adsorptive recovery stage, which comprises specially designed levels of irrigation and contact medium. A final demisting stage completes the process.

Additional recovery and/or treatment stages can be added to ensure that final emission levels are achieved. The plasticiser/solvent mixture could be re-used, depending on the nature of the manufacturing process, for instance in vinyl coating processes, such as wall or floor coverings.

3.4 Chemical leasing and other innovative business models

Chemical businesses are dependent on innovation and a continuous pipeline of innovative products and applications. This chapter provides an overview of known and successful chemical management business models.

3.4.1 Introduction to innovative business models

Greater spread and application of innovation in business models that reduce resource use has the potential to create multi-billion euro markets in the EU and overseas and achieve very substantial environmental and economic benefits. The actual spread of innovative business models currently covers a very broad range of sectors including industrial production of solid goods, fluids and ingredients as well as transportation, construction and maintenance, agriculture and public services. [23; p. 1]

3.4.2 Innovative chemical management business models

The chemical industry and the many companies that use its products have developed over time a linear business model in which raw materials are used to create valuable substances which are then, in turn, used to produce other products further down the value chain(s). Traditionally, chemicals are sold to customers, who become owners of substances and therefore responsible for their use and disposal. Their suppliers have a clear economic interest in increasing the amount of chemicals sold, which is usually related to negative releases to the environment. However, this is in opposition to the drive for resource efficiency and sustainability where the aim is to minimize resource use whilst maximizing added value.

Innovative service-based business models have the potential to resolve this problem. They aim to optimize the use of chemicals, save energy and encourage the recovery and recycling of chemicals. They also represent a better use of technical expertise and create an alignment of aims and business models and a stronger relationship between the manufacturers of chemicals and those who use them. Besides, they appear able to deliver benefits throughout the supply chain as well as wider benefits for society. [23; p. 3]

Chemical leasing

Chemical leasing (ChL) is a preventive and service-oriented business model that shifts away from high sales volumes of chemicals towards an integrated approach and extended producer responsibility throughout the entire life cycle of a chemical. Compared to conventional approaches, the concept of chemical leasing is much more service-oriented. In this business model, the customer pays for the benefits obtained from the chemical, not for the substance itself. Consequently, the economic success of the supplier is not linked to product turnover anymore. The chemical consumption becomes a cost rather than a revenue factor for the chemicals supplier. Companies will try to optimize the use of chemicals and improve the conditions for recycling in order to reduce the amount consumed, which, in turn, reduces the environmental pollution.

Without the ChL model, the appropriate (safe) use and disposal of chemicals would be the responsibility of the user of the chemicals. In the ChL business model, however, this “classical” role allocation is shifted towards the producer and provider of chemicals and the function performed by these chemicals, respectively. The responsibility of the producer and service provider is extended and may include the management of the entire life cycle.

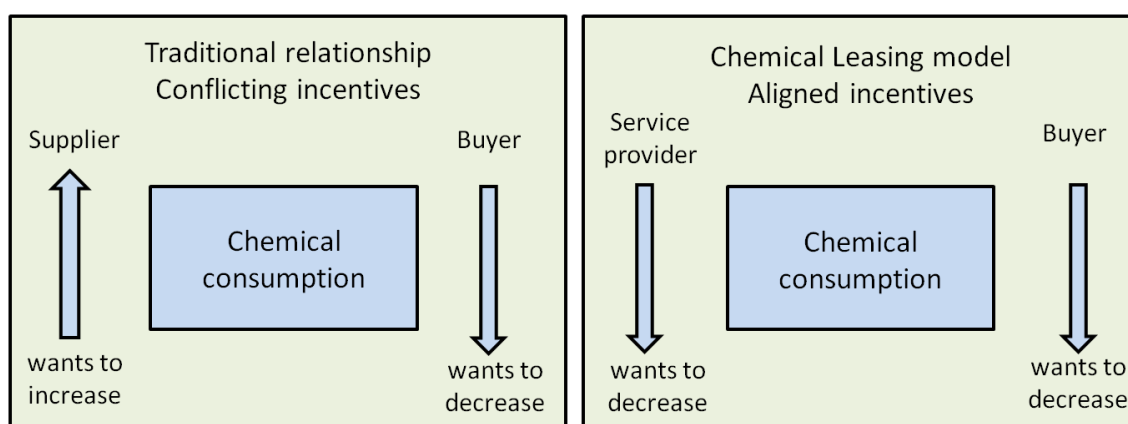


Figure 3-5: Traditional approach vs. chemical leasing model [based on 23; p. 9]

In Europe, the REACH regulation¹ has given a new legislative frame to the production, marketing and usage of chemicals. For certain hazardous chemicals (for example trichloroethylene), it requires authorization processes as a precondition of continued use. In this context, chemical leasing will play an increasingly important role in authorization processes because the business model requires the manufacturers to extend their responsibility and commitment to the safe and optimized use of chemicals. It is expected that in the near future certain chemicals requiring authorization will only be sold under a chemical leasing business model.

The following figure shows how technology and process improvements resulting from intensified collaboration can significantly reduce the consumption of chemicals [25]:

¹ More information about REACH:

http://ec.europa.eu/enterprise/sectors/chemicals/reach/index_en.htm

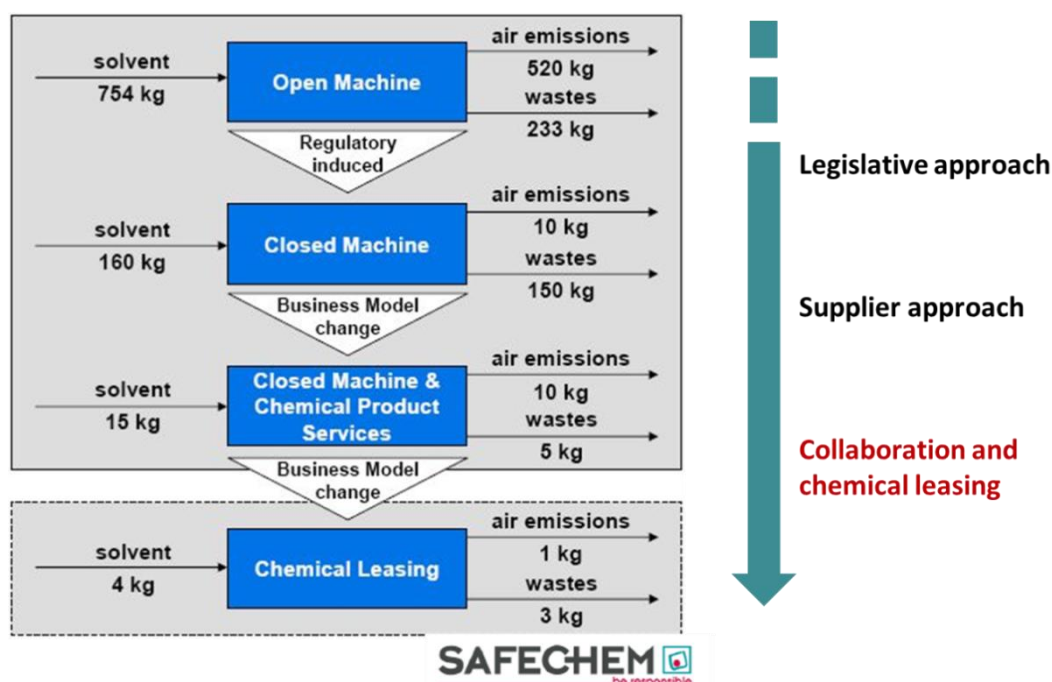


Figure 3-6: Example of consumption and emission reduction by technology and process improvements resulting from intensified collaboration [68 and SAFECHEM Europe GmbH]

The application of ChL models achieves economic advantages for all partners involved, provides specific solutions for efficient chemicals management and ways to reduce negative impacts on the environment. Since chemical products provide a broad variety of services such as “cleaning”, “coating”, “colouring” and “greasing”, the ChL model is applicable in a multitude of industry sectors [26].

Chemical Management Services (CMS)

Chemical Management Services (CMS) is a business model in which a customer purchases chemical services rather than just chemicals. These services can encompass all aspects of the chemical management lifecycle including procurement, delivery/distribution, inventory, use (including chemical substitute research), collection, monitoring/reporting, training, treatment, disposal, information technology and even process efficiency improvements. Each of these services poses its own costs and risks. Under CMS, the service provider is compensated based on the quality and quantity of services provided that reduce lifecycle costs, risks and environmental impacts of a chemical substance, and not on the volume of chemicals sold. Therefore, the service provider has the same objective as the customer: to reduce chemical use and costs. Both partners achieve bottom-line benefits through reduced chemical use, cost and waste. This model is now widely used in the automotive, aerospace and microelectronics sectors, where environmental benefits observed include reduced chemical use, reduced emissions and reduced waste generation, as well as substantial cost savings. A total average cost reduction of 30 per cent has been achieved in the first 5 years [23]. This model differs from ChL in that the unit of payment in ChL is the service provided by the chemical, which will always result in its efficient use, while in CMS the unit of payment is the whole service of chemicals management. This approach depends on the good management of the chemicals by the service supplier.

Closed-Loop Models

These models take a life cycle approach to materials used in goods and services and furthermore strive to keep materials within the economic system rather than letting them become waste. In the closed loop system, there is effectively no such thing as waste. The application of this approach starts by focusing on what is being delivered to the customer and how it can be achieved more efficiently.

More and more sectors and major businesses are moving towards closed-loop approaches in order to internalize major risks, protect against resource supply disruption, reduce environmental impacts and develop a better value proposition for customers. The benefits of this model are therefore broad and not only environmental in character.

For chemistry-using industries, this approach means not only taking responsibility for minimizing the impacts of the substances produced and sold from raw material sourcing right through to the end of product life, but also taking back the product at the end of its life and restoring it to a condition where it can be reused.

The approach ranges from extending the lifespan of a product (repair and remanufacture) to providing a service based on the effect a substance delivers rather than the substance itself. The latter is typically achieved by full recycling of the material with ownership retained by the provider.

Experience has shown that closed loop models work very well business-to-business but can be harder to implement along complicated supply chains or in business-to-consumer industries [24].

Feedstock foundation

This model focuses on petrochemicals, and typically consists of three to five business units. Feedstock foundation companies produce the essential building blocks for downstream players in the chemical industry and end markets, and concentrate on adding value to feedstock primarily through “smart” locations (advantaged feedstock, growth markets), large-scale facilities and leading process technology [26; p. 4]. Thus, this innovative business model is suitable for limited, large-scale businesses.

Chemicals platform

Chemicals platform companies typically consist of five to ten business units that span the entire chemical value chain. The platform of this model is a sort of “portfolio management company” that concentrates on the businesses, capabilities, markets and products loosely targeted at some of today’s mega trends such as health, energy, transportation, housing and construction. These companies consist of a portfolio of business units operating more or less independently according to the companies’ governance structure and actively managed for growth and synergy [26; p. 4].

Market maker

Market makers typically consist of one to three business units. This model focuses not on chemical end markets, but rather on selected end markets such as life science, agrochemicals, paints and coatings, and related technologies. Market makers focus on driving innovation based on the understanding of product performance and act on pervasive end-market trends, not simply customer input. These players make a significant investment in brand and distribution. They tend to have high growth with products that represent a limited share of customer cost and value chain [26; p. 4].

3.4.3 Additional sources of information

Websites

Chemical leasing website: a one-stop site to learn everything about this business model and to find helpful guidelines and recommendations for its implementation:

<http://www.chemicalleasing.org/index.htm>

Material on chemical leasing provided by UNIDO: <http://www.unido.org/chemical-leasing.html>

Chemical Strategies Partnership (CSP) website (USA): provides information on CMS and guidelines for its implementation: http://www.chemicalstrategies.org/implement_manualstools.php

Documents

DEFRA, UK: “A guide to chemical services” (2013); provides an easily accessible introduction to the chemical services model.

EU – DG Environment: “Promoting Innovative Business Models with Environmental Benefits” (2008); describes a selection of innovative business models that are economically profitable and also have positive environmental effects.

3.5 Prevention of major accidents

This chapter provides an overview of the state of the art in the prevention of major accidents, relevant for small and medium enterprises.

3.5.1 Importance of preventing major accidents

The advantages of reducing the likelihood and consequences of major accidents – including better protection of human health, the environment and economic resources – are well known [28; p.6-7]. An example of legislative measures supporting the prevention of major accidents is the Seveso Directive which obliges Member States of the European Union to ensure that operators have a policy in place to safeguard against major accidents [27].

EC Directive 96/82/EC (Seveso II²) definitions [27, article 3]:

Major accident: a major emission, fire or explosion, leading to serious danger to human health and/or the environment, immediate or delayed, inside or outside an establishment, involving one or more dangerous substances

Hazard: an intrinsic property of a dangerous substance, with a potential for harm

Dangerous substances: named substances or substances with certain generic hazardous properties, for example flammability

Community

Major accidents can cause death and serious injury to workers and the local population as well as significant long-term health effects. They can harm livestock, crops and water supplies, and cause considerable environmental damage. They may also result in major economic losses for the enterprise involved and the entire community.

Health and environment

Major accidents can have devastating impacts on human health and the environment. For instance, they can cause direct, immediate harm to workers and other persons in the vicinity who are exposed to the harmful chemicals or who are injured by an explosion or fire. Acute exposure to dangerous substances can also cause long-term health effects including chronic diseases and cancer. Additionally, people may suffer harm indirectly through their diet as a result of ingesting contaminated drinking water, agricultural products, fish, livestock and other food items spoiled by polluted air, surface water and soil.

The release of dangerous substances into the air, water and soil can have serious environmental impacts, killing animals and vegetation, poisoning water supplies used for drinking, fishing and irrigation, and rendering soil unfit for agriculture.

² The Seveso Directive (currently the Seveso II Directive) will be replaced by the Seveso III Directive on 1 June 2015.

Economic impact

In addition to the potential impact on human health, accidents can cause significant economic harm, both to the enterprise as well as to the community. The costs associated with response, clean-up and recovery, including health services provided such as medical treatment, can be quite significant.

It is obvious that the enterprise where the accident occurred may suffer significant economic losses (from, for instance, property damage, loss of jobs, having to stop operations for an extended period or even bankruptcy). What is less evident are the costs incurred by other industries in the vicinity of the accident. For example, an accident may pollute local water bodies increasing the costs of water used for drinking and agriculture, and causing significant damage to the fishing industry. In addition, suppliers and customers of the enterprise will be impacted.

3.5.2 Main cause of major accidents

The potential for major accidents has become more significant with the increasing production, storage and use of dangerous substances. Inadequate management is often recognized as the main cause of major accidents, specifically:

- Inadequate design;
- Inadequate maintenance and operation procedures;
- Inadequate assessment of the existing hazards and the associated risks in the facility;
- Inadequate staffing or training.

A detailed analysis of an accident will normally reveal three cause levels: basic, indirect and direct (Figure 3-7):

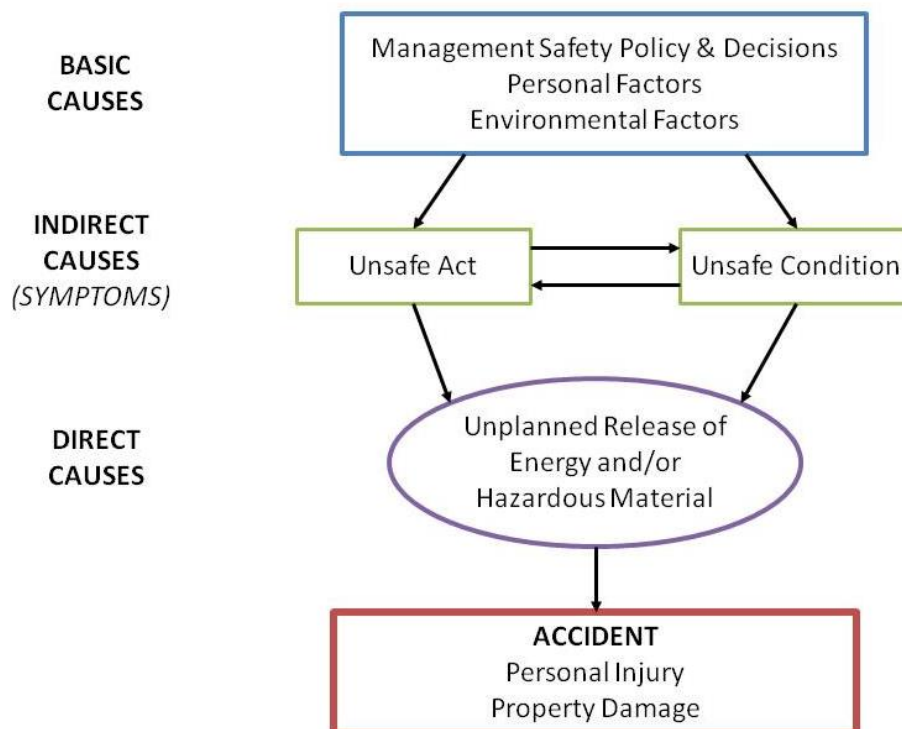


Figure 3-7: The three cause levels of an accident [31; p.350]

3.5.3 Motivation of SMEs and prevention of major accidents

Measures to prevent major accidents could lead to improved efficiency and lower production costs, as well as to improvements in the general health, safety and environmental performance of enterprises. Safe operations also protect the good will and reputation of industry, and foster improved relationships with members of the local communities.

At the local level, creating an effective major accident prevention plan might result in significant political implications. This could provide a platform for improving communication and trust between local leaders, the public and other stakeholders. Furthermore, communities typically blame local leaders for accidents if there has not been adequate warning or appropriate response.

3.5.4 Prevention of major accidents

Facilities that handle chemicals are actively engaged in dealing with risks to ensure the safety of their workers and their community. Most of their efforts focus on ensuring that the facility is designed and operated safely on a daily basis, using well-designed equipment, preventive maintenance, up-to-date operating procedures and well-trained staff [31; p.343].

It is recognized that the safe functioning of an enterprise depends on its overall management. Within this overall management system, the safe operation of an enterprise requires the implementation of a system of structures, responsibilities and procedures with the appropriate resources and technological solutions available [28; p.6-7].

Each enterprise should establish and implement a major accident prevention policy, which provides a basis for major accident prevention in order to minimize the likelihood of an accident and to protect human health, the environment and property. The elements of the safety management system (SMS) should be appropriate to the nature and extent of risks posed by hazardous installations and take the available resources into account [28; p.92-95].

A safety management system should address³ the organizational structure, practices, procedures and resources for implementing the major accident prevention policy and should include at a minimum the following items:

- Organizational structure (including roles, responsibilities, training, education, qualifications and inter-relationship of individuals involved in work affecting safety)
- Identification and evaluation of hazards (developing and implementing formal procedures to systematically identify and evaluate hazards – including their likelihood and severity – arising from normal and abnormal operations, and including the hazards arising from handling, production, transportation, storage or disposal of dangerous substances)
- Facilities and operational control (addressing design and construction as well as the procedures for safe operation, including maintenance of plants, processes, equipment and temporary stops)
- Management of change (planning and controlling changes in various areas such as organization, personnel, plant, processes including prestart-up reviews, maintenance and decommissioning, materials, equipment, procedures, software, design and external circumstances that might affect safety)
- Planning for emergencies (related to developing, adopting, implementing, reviewing, testing and, if appropriate, revising and updating emergency plans)

³ Based on the OECD Guiding Principles for Chemical Accident Prevention, Preparedness and Response (second edition, 2003).

- Monitoring performance (concerning the ongoing assessment of compliance with the safety policy and safety management system, and mechanisms for taking corrective action in the event of non-compliance)
- Audits and reviews (addressing the periodic, systematic assessment of the major accident prevention policy as well as effectiveness and suitability of the SMS)

Guidance for SMEs on specific safety management system elements

Small and medium enterprises (SMEs) are a very important part of the global economy, since they are the source of most growth in employment. They are flexible, adaptable and quick to respond to changes in the marketplace and new opportunities.

But if SMEs are to grow and become sustainable, enterprises must learn to consolidate and improve practices, to become more productive, to manage and mitigate risks more effectively and to understand their value chain and business environment more fully. This is why codes, standards, guidelines and frameworks that bring the experience of major companies to small companies in a useable way are so valuable.

UNEP's Responsible Production (RP) Framework for Chemical Hazard Management provides guidelines for small and medium enterprises. It provides a systematic, continuous improvement approach to chemical safety along the value chain. Moreover, the approach provides technical materials and tools to help SMEs understand hazards, control chemical exposure, reduce the risk of accidents and engage stakeholders [29].

The "Guidelines on a Major Accident Prevention Policy and Safety Management System" published in cooperation with the Major Accidents Hazards Bureau of the European Union provide very good advice on safety management systems. The publication provides guidance and descriptions on what is required by the Seveso II Directive [27].

Guidance on safety management systems

Development of a major accident prevention policy

The development of a major accident prevention document/policy is recommended as best practice. This document is intended to give an overview of how the company ensures a high level of protection for humans and the environment. Furthermore, it should clearly indicate the arrangements, structures and management systems required for each of the seven areas described in more detail further below [30; p.2].

The safety management strategy defines how safety and health are organized, measured and monitored. The development of a safety policy and safety plan is a key point to ensure that the strategies and procedures are implemented at all levels. All seven elements have to be incorporated into the system, including monitoring, audit and review processes which are essential components of the system [32; p.12].

Organisation and personnel

The safety management system should reflect the top-down commitment and the safety culture of the company's organization, translated into the necessary resources and direct responsibilities of personnel involved in the management of major accidents at all levels in the organization. Furthermore, it is helpful to identify the skills and abilities needed by such personnel, and ensure their provision [29; p.2].

The responsible production (RP) approach provides a systematic method of mapping key aspects (inputs, outputs, modes of production, stakeholders) related to reducing the risk of accidents. It often involves a quick on-site assessment of the company and consultation with management in order to gain a better understanding of the company's needs, priorities and potential areas for improvement.

Hazard Identification and Evaluation

Hazard identification and risk assessment are two major elements of the risk management process. They are necessary to be able to make decisions relating to risk, for example in terms of risk avoidance, reduction or transfer, or acceptance of the residual risk.

When undertaking a risk assessment, it is important to carefully consider the various possible approaches and methods available, and choose an approach/method that is appropriate for the particular circumstances, since all approaches/methods have their own strengths and weaknesses and none is perfect.

The methodology used for these processes is known as risk analysis or risk assessment. The spectrum of specific methods is broad and covers various degrees of depth and complexity in the analysis as well as various systems of investigation. Risk assessment methods include hazard mapping, check-lists, hazard and operability study (HAZOP), “What if” analysis and risk matrix⁴.

Techniques that are recommended for the analysis of major hazards include the “Dow Fire and Explosion Index” [33] and the “TNO Purple Book” (guidelines for quantitative risk assessment) [34]. The Responsible Production Toolkit (UNEP) provides tools which can help SMEs undertake hazard identification and risk assessment including prioritization of the identified risks.

Operational control

The company should prepare, update and keep readily available the information on process hazards, design and operational limits and controls resulting from the hazard identification and risk evaluation procedures. Based on these, documented procedures should be prepared and implemented to ensure the safe design and operation of plants, processes, equipment and storage facilities [29; p.5].

Straightforward guidelines on how to prepare a company’s process flow diagram can be found in the Responsible Production Toolkit. An objective is to clearly map the process flow in order to understand what the activities are and who is involved in them. This will help getting a better understanding of where chemicals are used and located. Process flow means both the sequence of activities that are undertaken in the company and the external activities that the company can influence within its business, ranging from the products and services the company procures to the products and services the company provides [29; p.14].

Management of Change (MOC)

According to the International Social Security Association (ISSA), management of change (MOC) is defined as “a systematic process to ensure the transition from an initially safe state to a new – again safe – state, along a safe path. The new state may be permanent or temporary.” In 2007, the ISSA published a practical guidance document on maintenance and changes in plants with high safety requirements [35]. This document is a valuable source for helping companies institute MOC.

Maintenance and changes are part of normal plant operation in the chemical industry, yet serious accidents often occur due to changes in processes. Changes frequently leading to unsafe conditions if not properly analyzed include the change of [35]:

- Construction materials
- Process parameters
- Inerting procedures
- Equipment parameters

⁴ An overview of the listed methods can be found in UNEP’s Flexible Framework for Addressing Chemical Accident Prevention and Preparedness, SG-2 Guidance on Risk Assessment (p. 122-125).

Such changes can be temporary or permanent, small or large. Nevertheless, any changes or modifications that result in deviations from the safety protocols (or safety management plan) are subject to a hazard analysis and risk assessment procedure. This is fundamental to all MOC activities.

According to the ISSA, typical items on a plant change form include:

- Administration (sequential number, date, plant, piping and instrumentation diagram)
- Description of the change (What will be changed? Why? What are the objectives?)
- Additional information (deadlines, cost)
- Schedule including the sequence of work (planning, preparation, main work, auxiliary work, termination) designed so that the work flow clearly appears from the entries
- Document update (P&I sheets, permits, explosion protection documents, safety checks and hazard analyses)
- Checks before start-up (process control system (PCS), pipes, pressure vessels, unloading points and filling stations)
- Approvals (with signature and date)

Further practical information relating to planning changes and accounting for safety in the various phases of changes (i.e. preliminary planning, basic design, detailed design, construction, commissioning and production) are found in the ISSA publication.

The following table provides an overview of MOC requirements according to the US Environmental Protection Agency (US EPA) and can be a useful guideline for implementing a company's MOC policy.

Table 3-7: Management of change requirements, Chapter 7.8 (2004) of the EPA General Risk Management Program Guidance [based on 36]

MOC procedures must address:	Employees affected by the change must:	Update process safety information if:	Update operating procedure if:
Technical basis for the change	Be informed of the change before start-up	A change covered by MOC procedures results in a change in any process safety information	A change covered by MOC procedures results in a change in any operating procedure
Impact on safety and health	Trained in the change before start-up		
Modifications to operating procedures			
Necessary time period for the change			
Authorization requirements for the proposed change			

Emergency planning

The safety management system should include the procedures necessary to ensure that an adequate emergency plan is developed, adopted, implemented, reviewed, tested, and, where necessary, revised and updated. The company should develop and maintain procedures to identify foreseeable emergencies arising from its activities, identified through hazard and risk assessment, and to record

this analysis and keep it up-to-date. Plans to respond to such potential emergencies should be prepared, and arrangements for testing and review on a regular basis should be included within the SMS. The procedures should also cover the necessary arrangements for communicating the plans to all those likely to be affected by an emergency [30; p. 6].

Proper assessments can only be made by undertaking a detailed safety and risk assessment audit of the operations, worker practices, company policies and the workplace environment [31; p.418]. Section 3 of the Responsible Production Toolkit gives recommendations on how to respond to the hazards and risks identified through reviewing the company's processes and activities. Furthermore, it provides guidelines on how to develop an appropriate response to chemical hazard issues and the associated impacts and how to communicate them to the concerned community. There are also a number of international publications that provide guidance on emergency planning related to major accidents, some of them being listed in the following paragraph.

3.5.5 Additional sources of information

Websites

Health and Safety Executive (**HSE**), UK website: provides a wealth of information and advice on work-related health and safety and the prevention of accidents: <http://www.hse.gov.uk/>

UNEP Safer Production website: provides a list of additional resources related to safer production: <http://www.unep.org/resourceefficiency/Business/CleanerSaferProduction/SaferProduction/AdditionalResources/tabid/101149/Default.aspx>

International Labour Organisation (**ILO**) Major Unit Operations and Processes: An Overview, <http://www.ilo.org/oshenc/part-xii/chemical-processing/item/378-major-unit-operations-and-processes-an-overview>

Documents

European Commission, Major Accidents Hazards Bureau (**MAHB**): “Guidelines on a Major Accident Prevention Policy and Safety Management System”

OECD: “Guiding Principles for Chemical Accident Prevention, Preparedness and Response” (second edition, 2003)

GTZ: “Chemical Management Guide for Small and Medium-Sized Enterprises” (2007).

UNEP: “Responsible Production Booklet; A Framework for Chemical Hazard Management for Small and Medium-Sized Enterprises” (2009).

UNEP: APELL Handbook (1988), Good practice in emergency preparedness and response (UNEP and ICM 2006), and other APELL-related materials

European Process Safety Centre (**EPSC**): “HAZOP: Guide to Best Practice” (second edition, 2008)

USA Risk Management Program (**RMP**): Section 112(r) of the amended Clean Air Act, with its regulations (40 CFR Part 68) - General guidance on risk management programs for chemical accident prevention

International Labour Organisation (**ILO**): “Code of Practice on the Prevention of Major Industrial Accidents” (1991)

European Process Safety Centre (**EPSC**), Brian J. Tyler, Frank Crawley, and Malcolm L. Preston, ed., *HAZOP: Guide to Best Practice* (2nd ed., 2008)

3.6 Safe handling of chemicals

This section provides a brief overview of:

- Hazards associated with the use and handling of chemicals
- Hazard communication in the form of labels and SDSs
- Performing a basic risk analysis
- Developing workplace operating instructions based on SDSs
- Preventive measures including:
 - Hierarchy: elimination, substitution, control: TOP hierarchy
 - COSHH Essentials Toolkit or ILO Toolkit (focus on essentials)

Chemicals are used in virtually all work activities, thus presenting certain chemical risks in a large number of workplaces all over the world. Many thousands of chemicals are used in substantial quantities, and many new chemicals are also introduced on the market every year. Hence, there is an urgent need to establish a systematic approach to safety in the use of chemicals at work.

An effective control of chemical risks at the workplace requires an efficient flow of information on potential hazards and the safety precautions to be taken from the manufacturers or importers of chemicals to the users. Employers should follow up on this information and ensure on a day-to-day basis that the necessary measures are taken to protect workers, and consequently the public and the environment.

Chemicals can be corrosive, reactive, flammable, explosive, oxidizing and inert, and contribute to serious health effects such as burns, rashes, kidney damage, lung damage, heart conditions, cancer, damage of the central nervous system, etc.

Routes of occupational exposure include:

- **Inhalation:** Nearly all materials that are airborne can be inhaled. This is the most common route. Gases and vapours can pass into the blood whereas solid particles are inhaled into the lungs.
- **Dermal absorption:** Skin contact with a substance can result in a possible reaction and many solids, liquids, vapours and gases can be absorbed through the skin.
- **Ingestion/swallowing:** Workers do not deliberately swallow materials they handle, however, the failure to wash hands, or eating in the presence of chemicals can lead to ingestion.
- **Injection:** Though uncommon, accidents occurring during the handling of sharp objects can result in the injection of a chemical into the bloodstream.
- **Ocular:** Chemicals are absorbed through the eyes or cause physical damage.

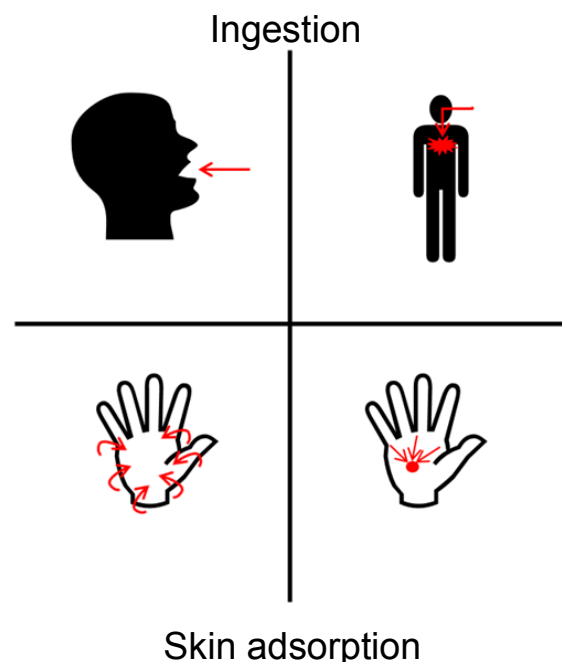


Figure 3-8: Routes of occupational exposure [74]

The safe use of chemicals involves several building blocks in which the GHS is a key element (see the following sub-chapter).

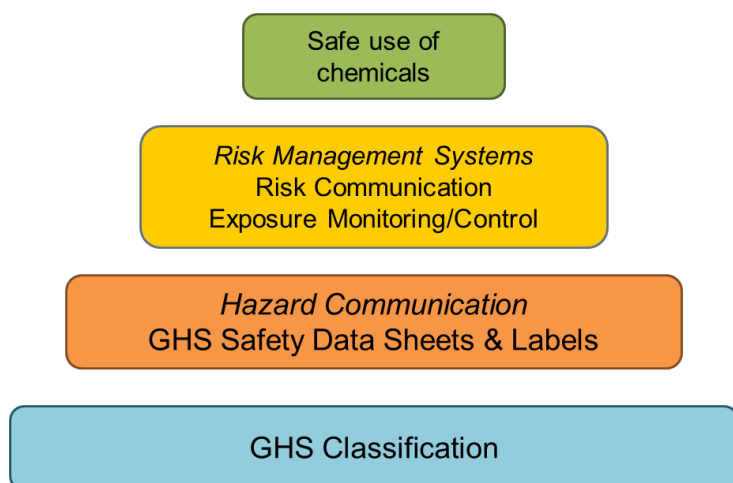


Figure 3-9: The building blocks for the safe use of chemicals

3.6.1 Globally Harmonized System of Classification and Labelling of Chemicals (GHS)

The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) is an internationally agreed-upon system, created by the United Nations. The GHS is a worldwide initiative to promote standard criteria for classifying chemicals according to their health, physical and environmental hazards. It is an international approach to hazard communication, providing agreed criteria for the classification of chemical hazards, and a standardized approach to label elements and safety data sheets (SDSs). The primary goal of the GHS is better protection of human health and the environment by providing chemical users and handlers with enhanced and consistent information on chemical hazards [37; p.63].

It is important to note that the GHS is currently being implemented in many countries, which means that users of chemicals will still encounter systems currently used in many major chemical producing countries.

The key elements of GHS include:

- Harmonized classification criteria
- Harmonized labelling elements
- Harmonized safety data sheet elements

The GHS uses the **signal words** “Danger” and “Warning”, **pictograms**⁵, **hazard statements**, and **precautionary statements** to communicate hazard information on product labels and safety data sheets.

Hazard classification

GHS consists of three major hazard groups:

- Physical hazards
- Health hazards
- Environmental hazards

⁵ Note: Not all categories have a symbol associated with them

Each hazard group consists of classes and categories (sub-sections of classes). For example, the hazard class “self-reactive substances and mixtures” has seven hazard categories (A-G). In general, the hazard categories are either in numerical or alphabetical order with “1” or “A” representing the most hazardous category.











Table 3-8: Hazard classification [based on 45]





Classes in the group “Physical Hazards”	
<ul style="list-style-type: none"> Explosives Flammable gases Aerosols Oxidizing gases Gases under pressure Flammable liquids Flammable solids 	<ul style="list-style-type: none"> Self-reactive substances and mixtures Pyrophoric liquids Pyrophoric solids Self-heating substances and mixtures Substances and mixtures which, in contact with water, emit flammable gases Oxidizing liquids
Classes in the group “Health Hazards”	
<ul style="list-style-type: none"> Acute toxicity Skin corrosion/irritation Serious eye damage/eye irritation Respiratory or skin sensitization Germ cell mutagenicity Carcinogenicity 	<ul style="list-style-type: none"> Reproductive toxicity Specific target organ toxicity – single exposure Specific target organ toxicity – repeated exposure Aspiration hazard
Classes in the group “Environmental Hazards”	
<ul style="list-style-type: none"> Hazardous to the aquatic environment (acute and chronic) 	<ul style="list-style-type: none"> Hazardous to the ozone layer

The following figure presents an overview of the pictograms used in the GHS and the UN Model Regulations on the Transport of Dangerous Goods (UNTDG) and their meanings.

Table 3-9: Pictograms used in the GHS and the UN Model Regulations on the Transport of Dangerous Goods (UNTDG) [based on 46]

Hazard pictogram	GHS hazard	Dangerous class labels (pictograms)	Dangerous good classes
	Explosive Self-reactive Organic peroxides	   	Explosive

Hazard pictogram	GHS hazard	Dangerous class labels (pictograms)	Dangerous good classes
	Flammable Self-reactive Pyrophoric Self-heating Emits flammable gas in contact with water Organic peroxides		<ul style="list-style-type: none"> • Flammability (liquid, solid or gas) • Pyrophoric • Emits flammable gas • Organic peroxide
	Oxidizers		<ul style="list-style-type: none"> • Oxidizer • Oxidizing gas
	Gases under pressure		<ul style="list-style-type: none"> • Non-toxic non-flammable gas • Flammable gas • Oxidizing gas • Toxic gas
	Acute toxicity		<ul style="list-style-type: none"> • Acute toxicity • Acute toxic gas
	Acute toxicity Skin irritant Eye irritant Skin sensitizer	No equivalent	
	Carcinogen Respiratory sensitizer Reproductive toxicant Germ cell mutagen	No equivalent	

Hazard pictogram	GHS hazard	Dangerous class labels (pictograms)	Dangerous good classes
	Eye corrosion Skin corrosion Corrosive to metal		Corrosive to metals
	Aquatic toxicity Not covered within the scope of workplace hazardous chemical requirements		Environmental hazard

Labelling

A label is the key to organizing chemical products for storage. Tanks, containers and bulk stores should be identified and marked with signs indicating the name/identity of the chemical product. The labels must be comprehensive and easily understandable to provide full information about each class and category of hazards according to the GHS.

Containers (including cylinders of compressed gases) must not be accepted without the following identifying labels:

- Identification of contents (for example chemical name)
- Description of principal hazards (for example flammable liquid)
- Precautions to minimize hazards and prevent accidents
- Appropriate first aid procedures
- Appropriate procedures for cleaning up spills
- Special instructions to medical personnel in case of an accident

Below, a model label is shown as adopted by the EU Classification, Labelling and Packaging Regulation (CLP Regulation), which aligns EU legislation to the GHS.

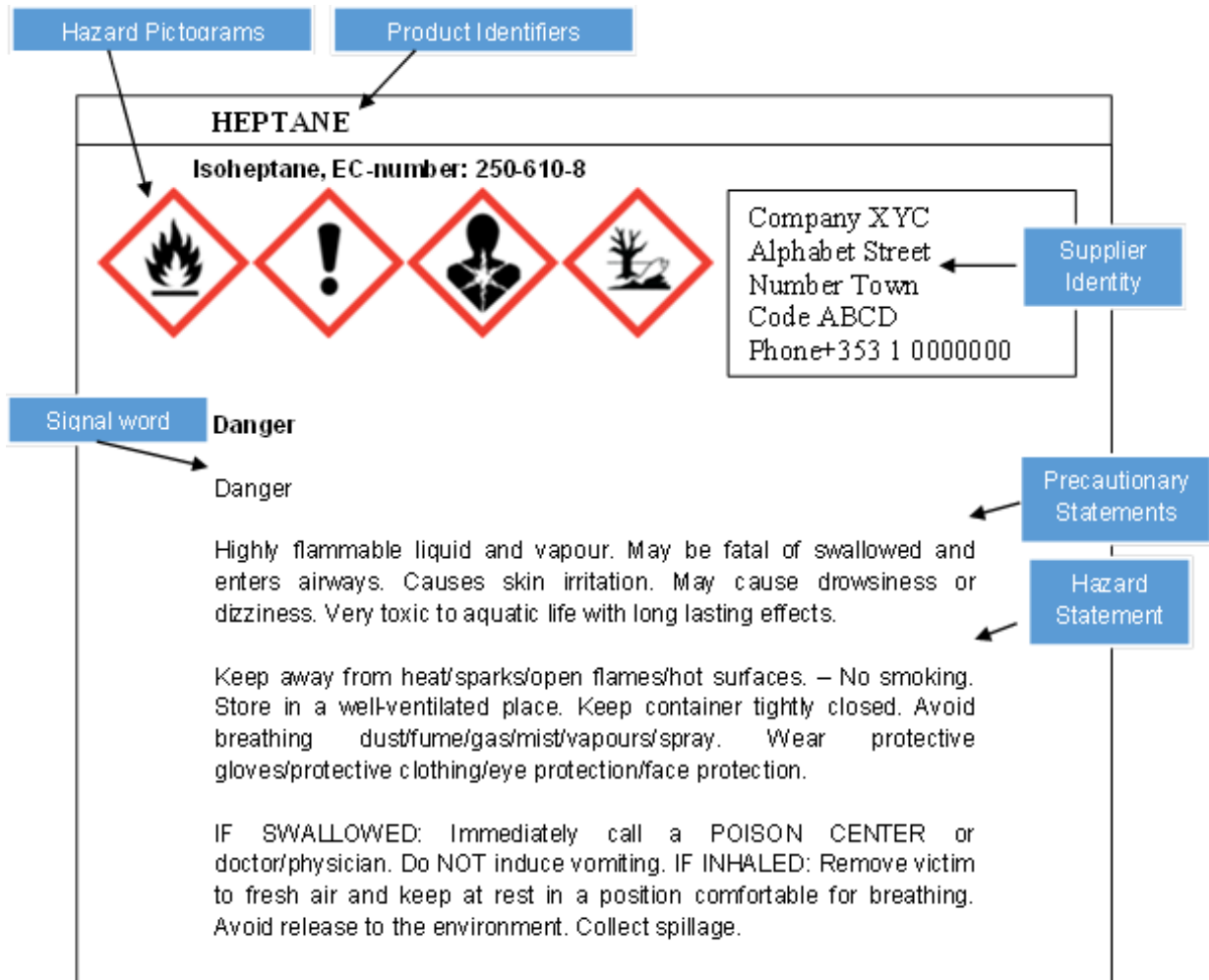


Figure 3-10: Model label according to the EU CLP (harmonized with GHS) [based on 45]

Additionally, a label for combining transport pictograms and GHS requirements is shown.

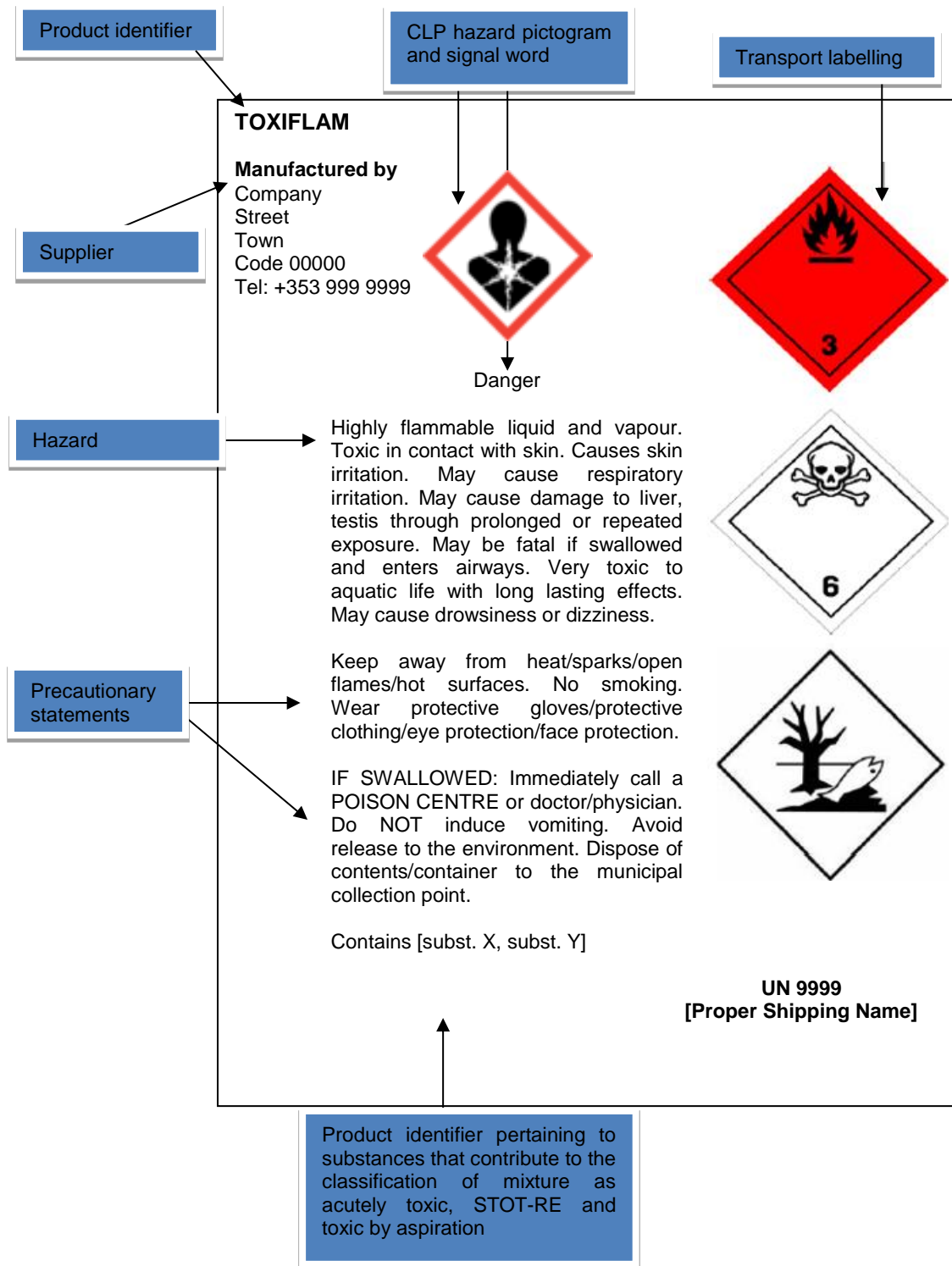


Figure 3-11: Label for combining transport pictograms and GHS requirements [based on 45 and 46]

GHS Safety Data Sheets

The GHS safety data sheets are key documents in the safe supply, handling and use of chemicals. They should provide comprehensive information about a chemical product that allows employers and workers to obtain concise, relevant and accurate information on the hazards, uses and risk management associated with the substance in the workplace.

An SDS provides the following information:

- Substance properties
- Health, environmental and physical-chemical hazards
- Storage, handling, transportation and final disposal
- Safety instructions for workers and measures to be taken in the event of a fire or accidental release as well as first aid procedures.

Based on this information, a hazard analysis is drawn up and workplace operating instructions are provided.

The SDS should contain 16 sections [38; p.5-9; p.39]

- | | |
|--|------------------------------------|
| • Identification | • Physical and chemical properties |
| • Hazard(s) identification | • Stability and reactivity |
| • Composition/information on ingredients | • Toxicological information |
| • First-aid measures | • Ecological information |
| • Fire-fighting measures | • Disposal considerations |
| • Accidental release measures | • Transport information |
| • Handling and storage | • Regulatory information |
| • Exposure control/personal protection | • Other information |

In many countries, the chemical producer is under legal obligation to provide an SDS. If the SDS is not delivered together with the chemical or provided electronically, the downstream user should request the SDS from the supplier (always the latest version).

Further information on the preparation of SDSs in compliance with the GHS was developed by the European Chemicals Agency (ECHA) and can be found in the section “Additional sources of information” further below. An example of an SDS complying with the EU CLP legislation is provided on the website indicated below⁶.

3.6.2 Hazard identification and risk analysis

The following section is based on UNEP’s Responsible Production Approach [39].

Understanding your operational processes

“Hot spots” are defined as:

- Places where you can observe inefficient handling or use of chemicals
- Particularly hazardous situations where chemicals are being stored or used and where the potential harm could be reduced or prevented by implementing appropriate control measures

To identify hot spots, you need to look at your operations in a different way. Rather than focusing on the end product, you need to look in a detailed way at the storage, handling and use of chemicals in the production process. Look specifically at how chemicals are being treated in steps involving their purchase, storage, handling and processing with the aim of spotting inefficiencies, waste, losses and risks. [40; p.20]

The hazard analysis should not only focus on production but include cleaning operations (cleaning of reactors and equipment), maintenance activities (preventive and corrective) and start-up/shut-down procedures.

⁶ http://reachteam.eu/english/compliance/SDS/docs/CLP_REACH_Compliant_SDS.html

Drawing up a chemical process flow diagram

The objective is to clearly map the process flow of chemicals in order to understand what the activities are and who is involved in them. This will help you to understand where chemicals are used and located (chemical streams). [39; p.14-15].

The basic strategy for a block flow diagram preparation is:

1. List all the steps and activities in the process.
2. Arrange the activities in sequence.
3. Discuss the sequence of activities with the relevant people in your company.
4. Review the flowchart with your workers and your business partners.
5. Check to see if they agree that the process has been drawn accurately.

Identification of chemicals, their quantities and the hazards involved in the process

The next step is to identify chemicals, their quantities and the hazards associated with their use at the company. It is important to identify the hazards for all chemicals involved in the process [39; p.14-15].

The objective is to systematically identify all chemical substances that are stored, handled and used at your business, along with information on their quantities and type of storage, and to classify them according to chemical product information, labels and GHS safety data sheets. Check this against the process flows to make sure you have not missed anything. Establish what information already exists within the company regarding chemicals (for example, purchasing records, stock control cards, inventories, suppliers' product information, GHS SDSs, etc.). List all chemical substances in an *inventory*. Begin with one department or process and proceed on a step-by-step basis until you have a complete inventory for your whole operation [41; p.16].

Assessing health, environmental, and economic risks

Tool 1.3 of the Responsible Production Toolkit provides a methodology to estimate the impact and likelihood of an accident situation. Note that the assignment of both the severity of impact and the likelihood of occurrence are *subjective* decisions, and therefore a multi-disciplinary team should be involved. The rating of the severity of a hazard should be based on the hazard and precautionary statements outlined in the SDS (hazard and precautionary statements are found in section 2 of the GHS SDS template). Further information on physical and chemical properties, stability and reactivity as well as health effects can be found in sections 9 to 11 of the GHS SDS template.

An essential component to assessing chemical risks is the creation of a compatibility matrix of hazardous substances. This tool can assist in determining the chemical reactivity of substances and mixtures (for example, toxic by-products or extreme heat generation). The Chemical Reactivity Worksheet⁷ predicts possible hazards resulting from the mixing of hazardous substances (chemicals) as well as data on whether the substance reacts with air, water or other materials. This hazard information can be entered in the risk matrix of the Responsible Production Toolkit.

3.6.3 Preventive and protective measures

Once you know where the chemicals are, what kind of chemicals you are handling and what their hazards are, you can use a hierarchy of controls to choose the best way of handling the chemicals safely as shown in the figure below.

⁷ The Chemical Reactivity Worksheet can be downloaded at: <http://response.restoration.noaa.gov/oil-and-chemical-spills/chemical-spills/response-tools/downloading-chemical-reactivity-worksheet.html>

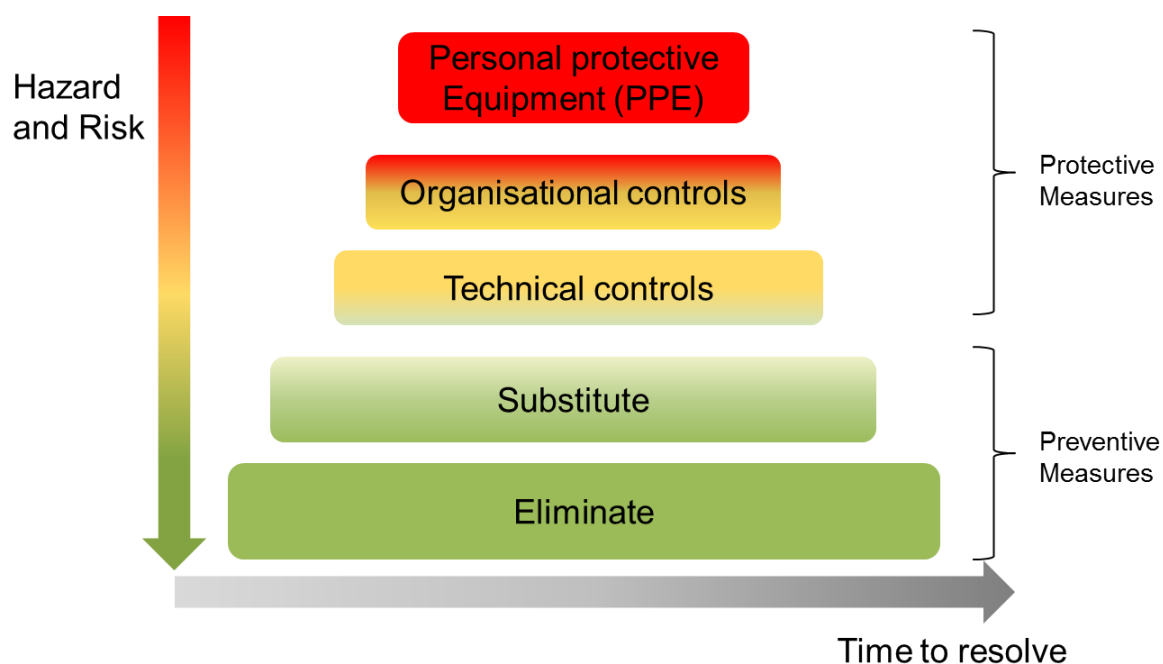


Figure 3-12: Hierarchy of steps according to the control strategy [41; p.22].

Preventive measures

Before the materials discarded from a process or a part thereof become waste, there are some measures that can be taken in order to prevent this conversion.

Eliminate

If you are not using a hazardous chemical, then there is no risk. Eliminating the hazardous chemical is the best way to control the risk. Consider whether you really need to use a chemical at all. For example, in recent years paint manufacturers have been able to eliminate hazardous solvents such as xylene [42; p. 23]. You could also consider whether it is possible to use a different process which does not require a hazardous chemical.

Substitute

It may be possible to replace your hazardous chemical by a less hazardous one. For example, you could replace isocyanate-based paints by water-based paints. You could also use a less hazardous form of the same chemical, For instance, using the chemical in pellet form rather than the powder could have a significant effect on reducing inhalable dust levels [42, p.23]. It is important that you consider hazards and potential exposure associated with the replacement chemical to ensure that no new hazard is introduced to the workplace.

The CatSub database (www.catsub.eu) provides a publicly accessible catalogue of more than 300 examples of substitution of hazardous chemicals including case studies that describe successful substitutions with less hazardous chemicals or hazard-free products. Furthermore, the European Agency for Safety and Health at Work provides some factsheets to support in the substitution of hazardous chemicals (Factsheet 34 – Elimination and substitution of dangerous substances⁸).

The internet portal SUBSPORT⁹ (SUBStitution Support PORTal – Moving Towards Safer Alternatives) combines information from several countries (for example, Denmark, Germany, Spain,

⁸ See <http://osha.europa.eu/en/publications/factsheets/34>

⁹ <http://www.subsport.eu/>

Sweden and the USA) regarding tools and case studies for the substitution of hazardous substances in products and processes with less hazardous alternatives. The portal is available in English, French, German and Spanish.

Protective measures

Protective control measures can be subdivided into the following TOP hierarchy:

- Technical control measures
- Organizational control measures
- Personal protective equipment

Technical control measures

Technical control measures are designed to move an air contaminant away from personnel and/or to create a barrier between a hazard and the employee. Some common types of engineering control measures are discussed below [42; p.2-3]

Chemical fume hoods

Chemical fume hoods are the primary containment devices used to protect personnel and the laboratory environment from hazardous chemicals that may become airborne through volatilization or aerosol formation.

Use a chemical fume hood when working with

- Flammable liquids
- Particularly hazardous substances that are volatile or that are in powder form
- Other volatile compounds
- Chemicals with a strong odour
- Other materials as indicated by the chemical- or lab-specific standard operating procedure

Local exhaust ventilation

Local exhaust ventilation is used with a localized source of chemical vapours that can be captured. Examples include snorkel-type exhaust and downdraft sinks. Local exhaust ventilation should only be installed with the involvement of the facility management for your building.

Isolation devices

These devices physically separate a contaminant-generating process from the work environment. They will often involve a sealed plexiglass box, and may be combined with local exhaust.

Process modification

Process modification involves changing the temperature or pressure at which a process is conducted, or using inert gas, or any other change in the procedure to reduce the likelihood of exposure or incidents.

Organizational control measures

The use of management and administrative procedures aims to reduce or eliminate exposure [37; p.24]

Look how the work is done and consider how employees are exposed to the chemical. Think about how the job could be done differently to avoid exposure. Where it is not possible to eliminate or isolate the chemical hazard, you should minimize exposure to it. This can be achieved by introducing written procedures in your workplace to:

- Minimize the number of employees who might be involved in a task, for example by introducing job rotation
 - Exclude other employees not involved in the task from the area where the chemical is being used
 - Provide training to your employees on the hazards and safe use of the chemicals they work with
-

- Ensure chemicals with hazardous properties are correctly stored
- Ensure emergency procedures are in place in the event of an accident, for example spillage

These procedures should be known by and available for all organizational levels.

Note: The posting of *operational procedures* highlighting the necessary precautions and methods of handling chemicals for certain tasks can help reduce the risk of accidents. The operational procedures (or working instructions) should contain the following sections: identification of the hazardous substances, hazards to human health and the environment, protective measures and rules of conduct, conduct in the event of danger, first aid and proper disposal. An example of how to obtain working instructions out of an SDS can be found in the annex of the document available at the link indicated below¹⁰.

Personal protective equipment (PPE)

The use of personal protective equipment (PPE) should be the last line of defence and not regarded as an alternative to other suitable control measures which are higher up the hierarchy. It should provide adequate protection against the risks arising from the hazardous chemicals to which the wearer is exposed, for the duration of the exposure, taking into account the type of work being carried out. [37; p.27]

Section 8 of the GHS SDS gives advice on steps needed to reduce exposure, including advice on appropriate PPE. Examples of precautionary pictograms to be included on an operational procedure sign are shown in the figure below:



Figure 3-13: GHS precautionary pictograms [based on 45]

Personal protective equipment can include:

- Eye/face protection (for example safety glasses, goggles, face shields)
- Skin protection (for example chemical-resistant footwear including shoes, boots and rubber boots, and clothing such as aprons or suits)
- Hand protection (for example gloves or gauntlets, disposable or otherwise, that are suitable for the task)
- Respiratory protection (for example respirators, masks or hoods that give adequate protection)
- Thermal protection (employees may need to be protected from excess heat or cold with appropriate clothing)

¹⁰http://www.baua.de/en/Topics-from-A-to-Z/Hazardous-Substances/TRGS/pdf/TRGS-555.pdf?_blob=publicationFile&v=2

There are several methods for determining the level of protection for PPE in the workplace. The US agency OSHA defines the four levels A, B, C and D, with A signifying the highest level of protection for skin and respiratory safety in the workplace. The method for determining the level of protection and the following table are provided in chapter 5 of the book “Practical Guide to Industrial Safety” [31].

Table 3-10: Level of protection and corresponding required personal protective equipment [based on 31]

Personal protective equipment	Level of protection			
	A	B	C	D
Hard hat				
Face shield or safety glasses				
Boots				
Inner gloves				
Outer gloves				
Work coveralls				
Chemical-resistant coveralls				
Chemical-resistant suit				
Fully encapsulating suit				
Air purifying respirator				
SCBA (self-contained breathing apparatus)/airline respirator				
Two-way radio				
Cooling system				

OSHA provides online tools to help in the selection of appropriate protective equipment, including eye and face protection¹¹ and respiratory protection¹². Furthermore, most suppliers provide the ability to search appropriate PPE according to an identified chemical.

Contractors' and maintenance activities

Two additional sources of accidents that are often neglected are *contractors' and maintenance activities* (preventive and corrective). Regular servicing and maintenance work is required due to the high stress placed on equipment in the chemical industry by exposure to very aggressive substances. Three kinds of maintenance work may be identified in the chemical industry: ongoing or daily maintenance work (executed without shutdown of the installation but where the equipment may be isolated), maintenance with a shutdown of the installation, and modification or construction of new units. Subcontractors may be involved in all three kinds of maintenance work. Outsourcing maintenance work is becoming the norm in the chemical industry.

In many countries, the company has legal responsibility for the safety of any personnel working within its installations, including contractors and external workers (revise local regulations carefully). Therefore, any occupational safety and health (OSH) management plan should include contractors and maintenance activities. Several fact sheets are available from the European Agency for Safety and

¹¹ <https://www.osha.gov/SLTC/etools/eyeandface/index.html>

¹² <https://www.osha.gov/SLTC/etools/respiratory/index.html>

Health at Work (EU-OSHA) to assist companies in integrating maintenance activities and any related (sub)-contracting¹³.

3.6.4 Online tools for controlling health risks from chemicals: COSHH Essentials

The COSHH Essentials website¹⁴ provided by the UK Health and Safety Executive is similar to the ILO International Chemical Control Toolkit¹⁵, but it goes a step further and provides direct guidance based on input to an interactive website. After entering data of processes and operations in the online tool¹⁶, users are given advice on a range of tasks involving chemicals, such as mixing or drying.

Details on relevant control measures such as “drum emptying” or “transferring liquid by pump” are available for download and are valuable tools for protecting workers.

3.6.5 Additional sources of information

Websites

UNECE (United Nations Economic Commission for Europe): provides more information about the GHS and the application of the GHS criteria:

<http://www.unece.org/trans/danger/publi/ghs/guidance.html>

HSE (Health and Safety Executive): UK website providing a wealth of information and advice on work-related health and safety, and guidance on the control of hazardous substances:

<http://www.hse.gov.uk/>

Documents

UNEP: Responsible Production Handbook. A Framework for Chemical Hazard Management for Small and Medium Sized Enterprises

HAS (Health and Safety Authority), Ireland: Your steps to chemical safety. A guide for small business

GTZ Chemical Management Guide for Small and Medium Sized Enterprises, 2007

3.7 Storage of hazardous chemicals

All substances or mixtures presenting one or several hazards that could have adverse effects on humans' and animals' health or life, harm the environment or damage infrastructures are considered as hazardous materials. The presence of these substances in a company requires special rules for handling, processing, disposal and, of course, for storage. The aim of this chapter is to present general and specific rules for the storage of hazardous substances in order to prevent fires, explosions, the formation of gases and toxic vapours, the pollution of soils, surfaces and groundwater, etc.

The literature is rich with information, and it is not possible to provide here an exhaustive list of the standards regarding the storage of hazardous substances. The objective of this chapter is to present the

¹³ <https://osha.europa.eu/en/publications/e-facts/e-fact-62-safe-maintenance-working-with-contractors-and-subcontractors/view> ; <https://osha.europa.eu/en/publications/e-facts/e-fact-66-maintenance-and-hazardous-substances/view> ; <https://osha.europa.eu/en/publications/e-facts/e-fact-67-maintenance-chemical-industry/view>

¹⁴ <http://www.hse.gov.uk/coshh/essentials/index.htm>

¹⁵ http://www.ilo.org/legacy/english/protection/safework/ctrl_banding/toolkit/icct/

¹⁶ <http://www.hse.gov.uk/coshh/essentials/coshh-tool.htm>

most relevant rules, applicable in an industrial context, in order to enable the safety manager (or equivalent) to analyze the storage conditions in the company, identify gaps and define where measures need to be taken to ensure compliance with standard storage policies. However, it is important to keep in mind that national regulations and safety values have to be complied with at any time.

3.7.1 Storage concept

A storage concept includes all the relevant information needed to ensure the safe storage of hazardous materials and compliance with regulations as well as environmental and safety requirements. It gives an overall view of the local situation and available measures. By drawing up a storage concept, the following objectives can be achieved [43]:

- The local conditions and measures are perfectly adapted to the hazards arising from the stored products.
- As a result of the overall consideration, conflicting measures are identified and may be adjusted.
- Legal requirements are met.

To achieve these goals, a storage concept must include the following information:

- A description of the local environment including storage conditions, physical properties of storage rooms and definitions of the stored substances
- The nature and the quantity of the hazardous substances
- Structural, technical and organizational measures

3.7.2 Classifications/categories



















Hazards

The hazards associated with chemical substances were presented in the previous chapters of this manual. The various properties need to be described in safety data sheets and other relevant documents, and marked on containers. The Globally Harmonized System of Classification and Labelling of Chemicals (GHS) is a standardized system to classify substances and hazards and was covered in Section 3.6.1, where the different hazards and their pictograms were described.

Storage classes (SC)

Based on the European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) [47] and the UN Recommendations on the Transport of Dangerous Goods [46], nine material classes (and additional subclasses) were defined, for which specific handling and storage rules were developed. Three of them are not dealt with here as they are too specific (infectious, radioactive and explosive materials). The categories are listed in the following table.

Table 3-11: Storage classes [based on 46 and 47]

Storage class	Substance properties	ADR/UN labelling	GHS labelling
SC 2	Liquefied gases or gases under pressure		
SC 3	Flammable liquids		
SC 4.1	Flammable solids		
SC 4.2	Substances liable to spontaneous combustion (auto-flammable)		
SC 4.3	Substances which, in contact with water, emit flammable gases		
SC 5	Oxidizing substances/organic peroxides		
SC 6.1	Toxic substances		
SC 8	Corrosive or caustic substances		
SC 9	Miscellaneous dangerous substances and articles, including environmentally hazardous substances		

Examples of hazardous substances and their reactions

As a general rule, the storage of chemicals must be organized in different areas, according to the storage classes defined above. Moreover, possible chemical reactions between substances that can be severe and dangerous have to be considered, for instance:

- When acids react with non-precious metals (aluminium, silicon, zinc or iron) or when alkali metals (sodium or potassium) come into contact with water, or just humidity from ambient air, hydrogen is created. Hydrogen is an extremely flammable gas and can be explosive when mixed with air.
- Powerful oxidants such as hydrogen peroxide can cause fires if they come into contact with organic materials such as wood, paper, cardboard, etc.
- Sulphuric acid mixed with caustic soda creates an important exothermic reaction, which can lead to overflowing or dangerous corrosive projections.

For this reason, the storage of chemical substances requires proper organization, taking into account the hazard of each substance separately as well as the potential reactions between them. The incompatibility rules are presented in chapter 3.7.3, whereas the next table [43] shows most frequently observed dangerous reactions.

Table 3-12: Dangerous reactions

Substance A	+	Substance B	=	Danger
Acids	+	Metals	=	Spontaneous combustion (gaseous hydrogen)
Oxidants	+	Organic substances	=	Fire, explosion
Sulphide	+	Acids	=	Toxic gaseous sulphurated hydrogen
Alkali metals	+	Water	=	Spontaneous combustion (gaseous hydrogen)
Acids	+	Bases	=	Exothermic reaction (heat emission)
Metal powders	+	Aqueous solution	=	Spontaneous combustion (gaseous hydrogen)
Metal powders	+	Air	=	Spontaneous combustion
Nitric acid	+	Organic substances or metals	=	Toxic nitrous gas
Chlorine bleach	+	Acids	=	Toxic gaseous chlorine

3.7.3 Technical solutions

General storage rules

The next chapters present the requirements that must always be met, for the storage of any hazardous material, including the waste generated by the use of these materials.

Marking and labelling

The hazardous substances must be stored in a specific place, room or cupboard, clearly identified and separated from the process areas. The hazard must be indicated and the access restricted.

Every container, from the smallest bottle to the largest tank, must be labelled, in order to provide immediate information on the substance contained and the related hazard. For more information about labelling according to the GHS, refer to Section 3.6.1.

Inventory and safety data sheets (SDS)

In order to have a complete overview of the situation and of the potential hazards in case of an incident (leakage or fire), the company systematically needs to register the stored hazardous substances, including:

- Maximum quantities for every category and updated currently stored quantities
- Storage position(s) on a map

The fire brigade must be informed about the inventory. Furthermore, safety data sheets of every substance must be registered and easily available. Ideally, copies of these SDSs are stored with the substances. They provide information about the hazards, the storage requirements and the expected reactions in case of an accident.

The manufacturers of hazardous materials have to provide safety data sheets with the products they are selling. These SDSs must be regularly updated to comply with national and international standards and requirements. Specific information about SDSs, as specified by the GHS, is provided in Section 3.6.1 in the subsection “GHS safety data sheets”.

Water protection

Every liquid must be stored on a catch basin in order to manage overflow, leakage or accidental spillage. The objective of containing the liquid and avoiding its dispersion is to prevent:

- Environmental contamination and human exposure
- Dangerous reactions

If the substances stored present a high aquatic toxicity, or if this toxicity is low, but the quantities stored are high (over 1,000 kg), the retention capacity must provide for 100% of the highest volume stored plus the retention of the water that would be used to extinguish a fire.

A flow to the sewage system or to surface water must be prevented. The position of evacuation grids must be checked. They might be covered. In case of a dangerous spillage, they must be covered by appropriate means (for example special bags).

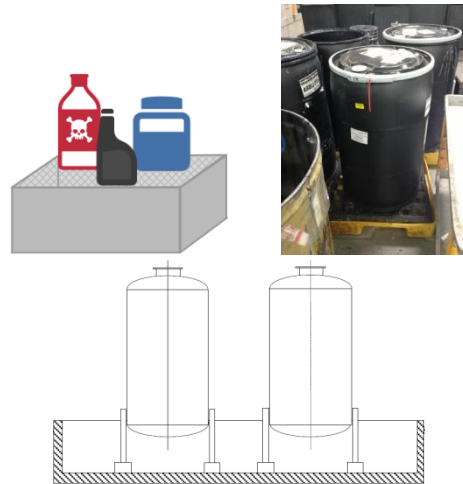


Figure 3-14: Different kinds of catch basins, according to the required volume [72], [23], [49]

Storage incompatibilities

Hazardous substances must be stored separately from any other non-hazardous material, and especially from food or drugs.

This matrix shows a classification of substances that, according to their hazardous properties, must not be stored together (red), can be stored together under certain conditions that have to be verified in the SDS (orange) or can usually be stored together without disadvantages (green).

Acids and bases must not be stored together.

Appendix 5: Storage shows storage incompatibilities for 16 substances commonly used in industry.

	○	-	-	-	-	-	+	-	-
	-	+	-	-	-	-	+	-	-
	-	-	+	○	-	-	-	-	-
	-	-	○	+	○	-	-	-	-
	-	-	-	○	○	○	○	○	○
	-	-	-	-	○	+	+	+	+
	+	+	-	-	○	+	+	+	+
	-	-	-	-	○	+	+	+	+
	-	-	-	-	○	+	+	+	+

Figure 3-15: Storage incompatibilities [based on 51]

Other safety and organizational requirements

- The flooring of the storage area must be impermeable. A special coating (sealing) will often be necessary, as concrete is permeable to many substances. This coating must be incombustible.
- The storage room and the facilities must be made of fire-proof material.
- The separation of the storage areas (or compartments) according to the storage categories must be clearly identified and labelled (flammable, toxic, corrosive, etc.).
- Other non-hazardous materials should not be stored in the same place (wrapping, paper, cardboard, spare parts, etc.).
- A substance must never be stored in a container that is not the original one, unless it has been specifically designed for this use (sufficient mechanic, thermal and chemical resistance).
- The containers must be protected from any mechanical or thermal influence (heat sources, falling objects, pressure through weight, etc.).
- Training must be conducted regarding chemical hazards and behaviour in case of an accident.

- There must be one responsible person (and one deputy) appointed for the storage area(s).
- Appropriate personal protective equipment (PPE) must be easily available and properly maintained.
- At least one eye shower must be installed. An emergency shower can be necessary.

Specific rules for each storage category

Storage category 2: Liquefied or under pressure gas

In case of accidental destruction or fire, pressurized containers can turn into dangerous projectiles. Hence, the following safety measures have to be taken:

- Gas bottles must be protected by a fence.
- Use natural or forced ventilation (air renewal 3 to 5 times per hour, extraction near the ceiling or the floor depending on the properties of the gas).
- If the flammable gas is heavier than the air, consider an explosive atmosphere extending from the ground up to 1 metre (Zone Ex 2¹⁷) [48].
- If the flammable gas is equal in weight or lighter than the air, consider an explosive atmosphere in the whole room (Zone Ex 2).

If the vapours or gases are heavier than the air, the openings should be located near the ground. If they are lighter than the air, the openings should be located near the ceiling.

Ammoniac or gaseous chlorine storage requires very specific storage conditions that are not described here.

Storage category 3: Flammable liquid [43], [44]

The vapours of these substances are usually explosive. In exposed rooms, active ignition sources¹⁸ must be avoided. Even the spark of a switch or an electrostatic discharge can set fire to these vapours. Therefore, smoking is strictly forbidden in those areas. In addition, electrical devices must be grounded and used so as to avoid ignition.

Explosive air or gas mixtures are often created in empty containers that have not been cleaned. In a fire situation, flammable substances burn fast or explode. Their flow accelerates the spread of fire.

Flammable liquids are divided into six categories, according to their flashpoint¹⁹.

F1 = Liquids with a flash point below 21°C

F2 = Liquids with a flash point of 21 to 55°C

F3 = Liquids with a flash point above 55 to 100°C

F4 = Liquids with a flash point above 100°C

F5 = Not easily flammable liquids

F6 = Non-flammable liquids



Figure 3-16: Storage of liquefied gases or gases under pressure [69]



Figure 3-17: Fire-proof cabinet [69]

¹⁷ According to ATEX regulations

¹⁸ Active ignition sources include flames, incandescent materials, hot surfaces or sparks emitted electrically, mechanically or electrostatically.

¹⁹ The lowest temperature at which a liquid can vaporize to form a combustible concentration of gas

The storage place shall meet the following requirements, according to the category of the liquid and the quantity stored:

Table 3-13: Storage place depending on the flammable liquid category and the volume (expressed in liters) [based on 44]

Storage place (small container/tank)	Indicative maximum authorized quantity [litres]	
	Categories F1 and F2	Categories F3, F4 and F5
Any type of room	5	30
Cabinet made of materials with low flammability	100	450
Premises with specific structural properties designed to resist fire	> 100	> 450

- For quantities over 100 litres (F1, F2) or 450 litres (F3, F4, F5), the flammable liquid must be stored in a specific room built with material showing specific fire-resistant properties and fire compartments. Consider an explosive atmosphere (Zone Ex 2) extending up to 1 metre above the installation that requires earthing.
- For quantities over 1,000 litres, each substance must be isolated in a specific fire compartment²⁰. Consider an explosive atmosphere (Zone Ex 2) extending up to 1 metre above the installation that requires earthing. For quantities over 2,000 litres, protection against lightning is required.

The storage area must be naturally or artificially ventilated:

- Natural ventilation is sufficient if the room is situated above the ground and has two openings directly connected to the ambient air. One of them has to be placed at a maximum of 0.1 metres above the ground. Each opening requires at least 20 square centimetres per square metre of floor area.
- Without sufficient natural ventilation, forced ventilation of the storage area is mandatory (3 to 5 air renewals per hour). The opening has also to be placed at a maximum of 0.1 metres above the ground.
- Storage areas in high-rise warehouses where flammable liquids are stored must be artificially ventilated.

Storage rooms (or racks) must be equipped with drip pans capable of collecting at least the volume of the biggest can, drum or intermediate bulk container (IBC).

Non-buried outdoor storage sites must meet the following requirements:

- Access is limited to authorized persons (a fence is mandatory, surveillance might be needed).
- A safety distance of 5 to 25 metres to neighbouring buildings must be observed, depending on the category, the volume of liquids and the risks for the neighbourhood (see Appendix 5: Storage; [44]).
- An adequately dimensioned drip pan providing for at least the volume of the biggest tank must be installed.

Dusts can be explosive and therefore dust deposits must be avoided and regularly cleaned.

- For quantities over 1,000 kg, the substances must be isolated in a specific fire compartment.

²⁰ A fire compartment is an area encircled by fire breakers (walls and ceiling must be fire-resistant) in order to prevent fire or smoke from spreading to other areas.

Storage category 4.2: Substances liable to spontaneous combustion (auto-flammable)

These substances can ignite very fast when in contact with the air, even in very low quantities. Examples include phosphor and freshly prepared metallic powders.

- Auto-flammable substances must never be stored outdoors.
- The storage area must be protected from any heat source. Ambient temperature should be controlled.
- They must not be stored with combustible, explosive or flammable substances.
- For quantities over 100 kg, the substance must be isolated in a specific fire compartment.

Storage category 4.3: Substances which, in contact with water, emit flammable gases

The reaction usually releases heat and the gas can ignite spontaneously. Examples include calcium and zinc powder.

- These substances must be stored in a dry place in hermetically closed containers.
- They must not be stored with halogens (fluorine, chlorine, bromine).
- For quantities over 100 kg, the substance must be isolated in a specific fire compartment.
- Specific extinguishers must be available and the sign “Do not extinguish with water” must be visible.

Storage category 5: Oxidizing substances/organic peroxides

These substances form highly flammable or explosive mixtures with any combustible material, flammable substance or just paper, sugar or wood. Notably **organic peroxides** must be carefully stored and handled, as they usually burn explosively.

- These substances must not be stored with combustibles (not even non-hazardous materials such as wood or paper) or caustic substances.
- They can be stored in the same room as other substances, but in a separate specific metal box or cupboard. Some organic peroxides must be refrigerated (well below their decomposition point).
- For quantities over 100 kg, the substance must be isolated in a specific fire compartment.

Storage category 6.1: Toxic substances

Even in very small quantities, these substances can be very harmful, even fatal.

- The storage must be secured and only accessible to authorized persons (key or code).
- For quantities over 1,000 kg, the substance must be isolated in a specific fire compartment.

Storage category 8: Corrosive and caustic substances

These substances can be very harmful, even fatal, in case of contact with the skin, the eyes or in case of ingestion or inhalation of vapours.

- They must not be stored with substances that form toxic gases with acids, or with combustible and oxidizing substances.
- Containers and catch basins must be resistant to corrosion (special plastics).
- Acids and bases must be physically separated and stored on distinct catch basins.
- For quantities over 1,000 kg, the substance must be isolated in a specific fire compartment.
- Storage rooms (or racks) must be equipped with drip pans capable of collecting at least the volume of the biggest can, drum or intermediate bulk container (IBC).

Storage category 9: Miscellaneous dangerous substances and articles, including environmentally hazardous substances

This group includes halogenated hydrocarbons such as perchloroethylene, chloroform or methylene chloride. Concrete is permeable to these highly pollutant substances.

- The catch basin must be capable of collecting at least the volume of 100 per cent of liquids utile volume (real volume occupied by the substance) and not only 100 per cent of the biggest container.
- The storage floor must be coated (sealed).

3.8 Fire protection

Every company should have a fire protection concept. Industries storing or processing any kind of flammable substances are by nature more exposed to the risk of fire, and developing a fire protection concept is therefore mandatory.

This chapter aims primarily at explaining the procedures and working methods for drawing up a fire protection concept and defining associated measures designed to reduce the fire risk.

Fire protection has the following objectives:

- Prevent fire occurrence and fire/smoke propagation
- In case of a fire, ensure effective response
- Provide health protection to persons, rescue teams and animals through safe escape routes
- Protect property (movable and immovable) and the environment

The organization of fire protection must comply with national and regional legislation. As presented in the figure below, it includes the two main aspects fire prevention and rescue procedures.

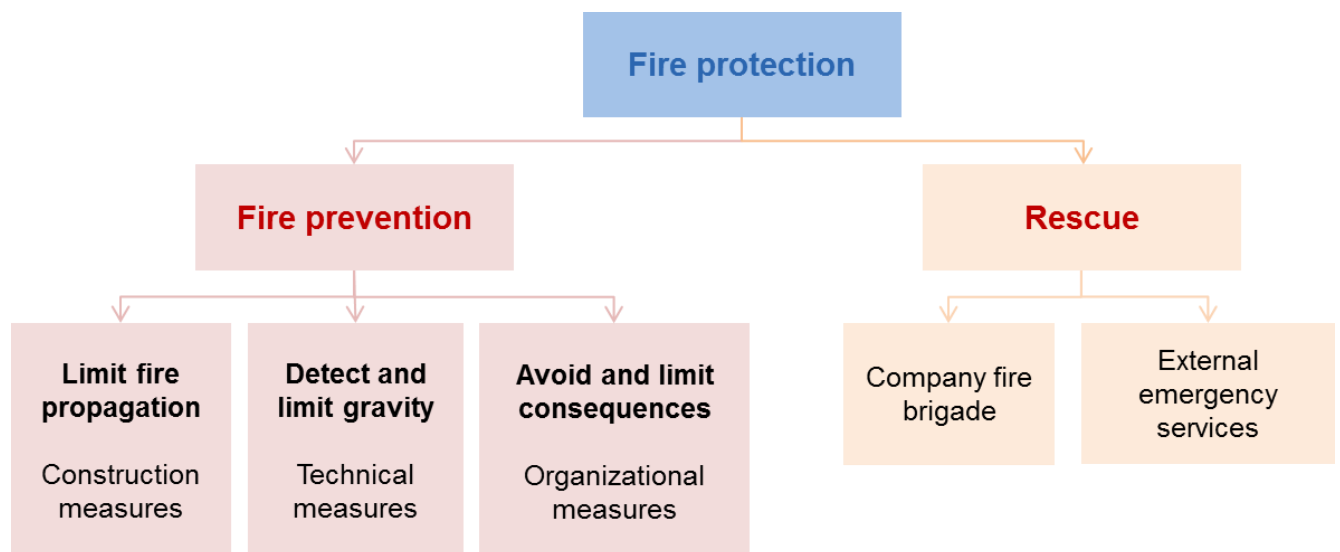


Figure 3-18: Fire protection [72]

Prevention includes structural, technical and organizational measures to limit, detect and avoid the risk of fire. The rescue phase covers support from internal and external emergency services and the fire brigade.

A fire protection concept should include all essential protection measures in terms of construction, technology, processes and organization likely to achieve the objectives of protection.

A fire protection concept is the result of a methodical procedure, as shown in the Figure 3-19, where a range of essential protection measures (structural, technological, process-based, organizational) are planned, taking into account the current situation, the identified hazards and the protection objectives. The concept should ideally be integrated in the planning of new facilities but can as be included in the conversion or restoration of already existing buildings [55].



Figure 3-19: Fire protection concept [72]

3.8.1 Classification/categories

Hazardous materials (hazard inventory)

The Table A6-1 presents the main hazardous material classes affected by fire or explosion hazards, including GHS pictograms and statement codes for different classes of flammable, explosive and oxidizing materials as well as gases under pressure.

The first step of a fire protection concept is to draw up an inventory of flammable, explosive, gaseous and oxidizing materials used in the company in order to define the concerned materials, their quantities and the conditions of storage, handling, processing and disposal.

Fire activation risk (hazard inventory)

The probability of accidentally setting fire to a tank of benzene is higher in a production area (where movements, heat sources or physical dangers are likely to be present) than in a secured storage site. The diagram below shows the increase in probability of the fire activation risk depending on the environmental context and the related physical constraints.

The fire activation risk can be defined as the probability of realization of the risk, depending on the environmental context and related physical constraints. It increases as shown in the diagram below:

- Storage
- Storage + process
- Storage + process + distillation/condensation
- Storage + process + distillation/condensation + pressure (storage and/or process)



The evaluation of the fire activation risk is the basic information to be considered in the fire risk assessment, as shown in Based on the categories defined by the risk analysis, appropriate measures can be taken in relation to construction, technology and organization in order to reduce the fire risk.

The following sections are inspired by the CFPA Guidelines “Fire protection on chemical manufacturing sites” [52] and “Safety distances between waste containers and buildings” [53].

Construction measures

The global purpose of applying structural measures is to limit fire propagation. These measures prevent the propagation of a fire by using suitable construction materials and confine the fire through fire compartments.

Table 3-16: Fire protection – Construction measures (non-exhaustive list) [based on 52]

Construction measures	Fire risk		
	Basic	Medium	High
Maintain safety distances to other buildings (2.5 metres), especially for premises where hazardous products are stored.	X	X	X
Use non-combustible building materials, especially for supporting structures and exterior walls.	X	X	X
Separate different types of activities in separate fire-compartments (administration, storage, production).	X	X	X
Limit the size of the fire compartments, especially of those with a high fire hazard.	X	X	X
Adapt the fire resistance of the compartments to the amount of flammable/explosive products and the fire activation risk.	X	X	X
Provide enough safe escape routes.	X	X	X
Install drainage and spill control systems designed to contain leakages and firefighting water.	X	X	X

In addition, the following internal and external causes can increase the fire activation risk and might be considered in the risk analysis:

Table 3-14: Internal and external hazards [based on 54]

Internal hazards	External hazards
<ul style="list-style-type: none"> • Ignition sources • Shortage of facilities and missing or damaged fire safety equipment • Lack of organization • Lack of ability to respond to an emergency (lack of training) 	<ul style="list-style-type: none"> • Arson • Natural disasters • Proximity of neighbouring buildings

Fire risk evaluation (risk analysis)

Based on the information collected through the hazard inventory, a rough assessment of the fire risk can be performed, considering the “Largest Individual Quantity” (LIQ) and the “Total Quantity” (TQ) of material identified in the area and the constraints on these materials. The figure below shows how this information can be used for the allocation to one of the three risk categories in order to define the level of protection measures required. The matrix presented here applies to solvents with a boiling point of up to 150°C [52].

Table 3-15: Determination of the fire risk category [based on 52]

Constraints	Largest Individual Quantity, LIQ (t), Total Quantity, TQ (t)							
	<0.5 LIQ	<1 TQ	<1 LIQ	1-10 TQ	<5 LIQ	10-30 TQ	<10 LIQ	>30 TQ
Stored in tanks, receptacles, bulk containers, drums	Green	Green	Green	Green	Yellow	Yellow	Red	Red
The above and processed in reactors	Green	Green	Yellow	Yellow	Yellow	Yellow	Red	Red
The above and distilling, condensing	Yellow	Yellow	Yellow	Yellow	Red	Red	Red	Red
The above and/or processing under pressure	Red	Red	Red	Red	Red	Red	Red	Red
Category 1: Basic fire risk	Basic fire protection measures are sufficient.							
Category 2: Medium fire risk	Additional fire protection measures are required.							
Category 3: High fire risk	Additional fire protection measures are mandatory.							

In order to define specific measures, the fire risk should be assessed separately for each area.

3.8.2 Technical solutions (risk reduction measures)

Based on the categories defined by the risk analysis, appropriate measures can be taken in relation to construction, technology and organization in order to reduce the fire risk.

The following sections are inspired by the CFPA Guidelines “Fire protection on chemical manufacturing sites” [52] and “Safety distances between waste containers and buildings” [53].

Construction measures

The global purpose of applying structural measures is to limit fire propagation. These measures prevent the propagation of a fire by using suitable construction materials and confine the fire through fire compartments.

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Use non-combustible building materials, especially for supporting structures and exterior walls.	X	X	X
Separate different types of activities in separate fire-compartments (administration, storage, production).	X	X	X
Limit the size of the fire compartments, especially of those with a high fire hazard.	X	X	X
Adapt the fire resistance of the compartments to the amount of flammable/explosive products and the fire activation risk.	X	X	X
Provide enough safe escape routes.	X	X	X
Install drainage and spill control systems designed to contain leakages and firefighting water.	X	X	X

In addition, the following information should be observed:

- The minimum horizontal safety distance between combustible objects and buildings is 2.5 metres. Certain situations require a larger safety distance (4, 6 or 8 metres) depending on the content, number and volume of the containers. Other parameters can affect this safety distance. Interested readers can find more detailed information in the corresponding guideline published by CFPA Europe [53].
- Buildings where flammable products are stored and handled must be made of non-combustible materials, including the insulation in roofs and walls. Floors of multi-level buildings, open structures and load-bearing structures should preferably be made of concrete.
- The maximum size of a fire compartment is about 3,200 square metres.
- The drainage and spill control systems must be designed for simultaneous flow of flammable liquids and fire-fighting water away from the building.
- It is essential that there is enough retention capacity for the firefighting water, especially if the products stored are dangerous to the aquatic environment or the soil.

Technical measures

Technical measures are settled to detect the fire risk by using alarm, fire or gas detection and to limit the impact by using water, extinguisher or sprinkler system.

Specific installations and devices are needed to protect an object from fire risk [52].

Table 3-17: Fire protection – Technical measures (non-exhaustive list) [based on 52]

Technical measures	Fire risk		
	Basic	Medium	High
Provide air handling and smoke exhausting systems (automatic + manual)	X	X	X
Provide manual firefighting equipment in adequate quantity (internal fire hydrants, fire extinguishers, etc.)	X	X	X
Provide manual alarm points	X	X	X
Provide an automatic fire detection system		X	X
Provide an automatic fire extinction system (with adequate extinguishing agents)			X
Provide a gas detection system			X
Install a lightning rod for all production buildings with significant amounts of flammable or explosive products	X	X	X
Install a safety lighting system	X	X	X
Provide sufficient fire water capacity	X	X	X

Furthermore, the following items have to be considered:

- The maximum distance between internal fire hydrants should be around 75 metres.
- Manual fire alarm points must be strategically located throughout the site and production units. Alarm points need to be provided at 60 metre intervals.
- Fire detection systems are mandatory in areas with low manning levels (automated plants). The system has to be strategically positioned in order to detect fires starting inside processing equipment.
- Gas detection systems should be provided where potential leak sources could occur (pumps, compressors, tank cars, control rooms, etc.) in order to be used for emergency functions like shutdown of processes and/or activation of emergency ventilation.
- According to evaluations of firefighting statistics, fire water volumes of 8,000 l/min up to 12,000 l/min are required without fixed extinguishing systems. The water supply should provide fire water for a minimum of two hours and preferably 3 to 4 hours. The water retention capacity must be designed accordingly.



Figure 3-20:
Fire alarm [72]



Figure 3-21:
Gas detector [72]

Organizational measures

Organizational measures are implemented to avoid and control the impact of a fire and include the training of employees, the maintenance of equipment and the provision of safe escape routes.

Table 3-18: Fire protection – Organizational measures (non-exhaustive list) [based on 52]

Organizational measures	Fire risk		
	Basic	Medium	High
Establish a preventive maintenance programme for all equipment, including fire protection equipment	X	X	X
Appoint an adequately trained person responsible for fire protection	X	X	X
Organize an employee training programme		X	X
Organize a training programme for visitors			X
Develop an escape and emergency plan		X	X
Organize evacuation exercises with local emergency services		X	X

Responsibilities include the coordination and implementation of the fire protection measures, focusing in particular on the following points:

- An internal inspection system should be implemented to ensure the periodical checks of installations and organizational measures that are relevant to fire protection.
- A person responsible for fire protection must be appointed and given practical training.
- All employees must receive periodical training on fire safety and emergency procedures.
- The fire protection documentation such as escape and emergency plans has to be continually updated and made available in every building in case of an emergency. An example is provided in Appendix 6: Fire protection)

3.9 Management of chemical waste

Out of 5 to 7 million known chemical substances, more than 80,000 are used by companies in their production processes and operations. Numerous new chemicals are developed and produced every year. Today, almost every company uses some type of chemicals and generates chemical waste. Those enterprises which effectively manage chemicals and chemical waste can gain concrete benefits.

In general, hazardous waste is any waste or combination of waste which may have detrimental effects on the environment or human health because of its specific nature. These wastes not only pose risks and hazards because of their nature but also have the potential to contaminate large quantities of otherwise non-hazardous wastes if allowed to mix. [40; p. 9]

Benefit by reducing costs and environmental impact

Chemicals can represent a major part of the production cost for companies. Any measures that can be taken to reduce the loss, waste, contamination and expiry of these substances will bring cost savings to companies and, at the same time, reduce their environmental impact.

Benefit by becoming more competitive

By improving the management of chemicals and chemical waste, companies that are striving to achieve certification under management system standards such as ISO 9000 (quality) and 14000 (environment) will gain synergies. Many of the activities required for Environmental Management Systems (EMS) certification are aimed at reducing the use of hazardous substances, protecting the health of workers and reducing negative effects on the environment.

Benefit from improving workers health and safety

Reducing health and safety risks for employees improves their motivation and productivity and reduces absenteeism due to injury and illness.

3.9.1 Waste management options

In Europe, waste producers have a statutory duty to consider the **waste hierarchy** when deciding how to deal with waste.

Hazardous waste hierarchy

The waste hierarchy is a concept at European level that provides a preferred order of priorities for selecting, ranking and deciding upon waste management options with the aim to conserve resources and to minimize environmental damage. It gives top priority to preventing waste in the first place. When waste is created, it gives priority to preparing it for re-use, then recycling, then recovery, and last of all disposal (for example landfill).

In the European Union Waste Framework Directive (2008), the waste hierarchy has five steps: prevention, preparing for re-use, recycling, other recovery (for example energy recovery) and disposal [56, p. 3].

Prevention means measures taken before a substance, material or product has become waste in order to reduce:

- The quantity of waste, also through the re-use of products or the extension of the life span of products
- The adverse impacts of the generated waste on the environment and human health
- The content of harmful substances in materials and products

Re-use means any operation by which products or components that are not waste are used again for the same purpose for which they were conceived.

Preparing for re-use means checking, cleaning or repairing operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing.

Recycling means any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes. It includes the reprocessing of organic material but not energy recovery or the reprocessing into materials that are to be used as fuels or for backfilling operations.

Recovery means any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.

Disposal means any operation which is not recovery even where the operation has a secondary consequence, the reclamation of substances or energy.

Other recovery is not specifically defined in the revised Waste Framework Directive, although ‘energy recovery’ is referenced as an example. Since the term ‘other recovery’ is explicitly excluded from the definition of recycling, ‘other recovery’ can be considered the processing of wastes into materials to be used as fuels or for backfilling.

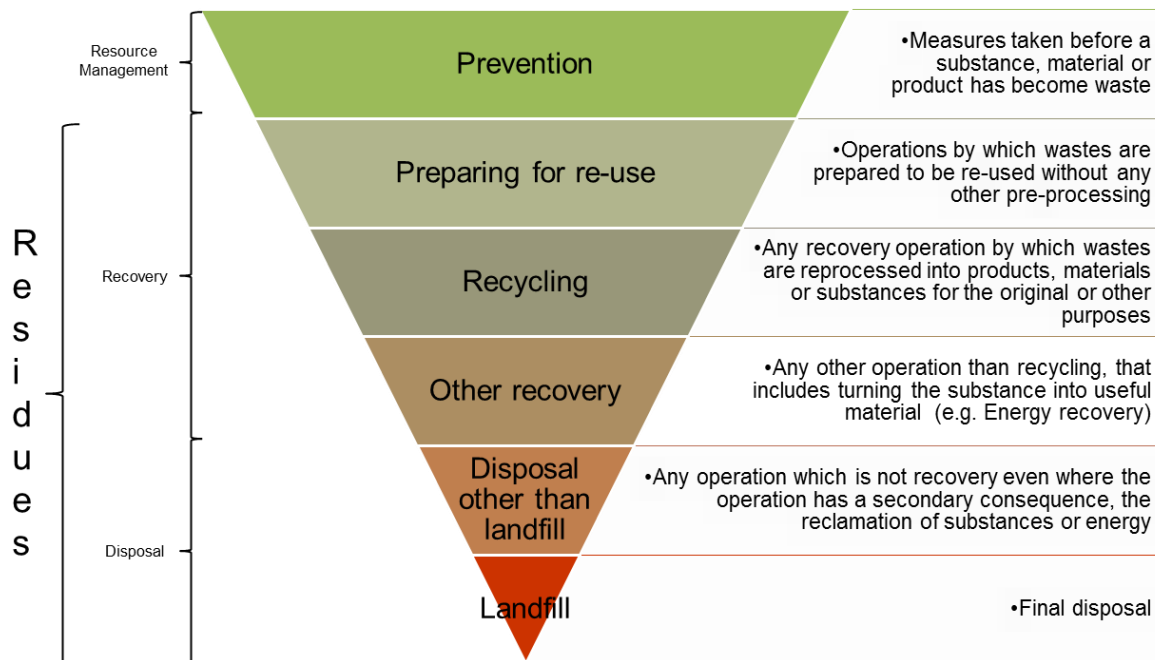


Figure 3-22: Hazardous waste hierarchy [based on 56]

3.9.2 Hazardous waste management

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal defines the **environmentally sound management of hazardous wastes** as “taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner which will protect human health and the environment against the adverse effects which may result from such wastes” [60; p. 17].

Therefore an overarching objective of the sound management of hazardous waste is to minimize the negative effects of the generation and management of hazardous waste on human health and the environment.

A very useful flow diagram to start a hazardous waste management plan, is shown in the document “Guidance on applying the waste hierarchy to hazardous waste” by DEFRA [56, p. 15].

Handling of hazardous waste

Adequate handling of hazardous waste is an integral part of the waste management system. The list below provides an overview of good management practices that help avoiding accidents:

- Train personnel on safe procedures to transfer chemicals to waste containers.
- Ensure that waste containers are in good condition.
- Check whether waste containers are compatible with the waste type they are expected to contain.
- Keep an adequate spill control kit nearby. The kit should be big enough to control the release of the largest type of container in the storage area. Clean up spills quickly.
- When handling waste containers, use mechanical aids such as drum lifts, drum hand trucks and drum dollies. Do not roll drums on their side or edge.
- Make sure container caps are secure.
- Train personnel on spill clean-up procedures.
- Maintain good general housekeeping. Keep aisles and walkways clear [61].

Identification, classification and labelling of hazardous waste

The hazardous waste identification and classification process is the crucial first step in the hazardous waste management system.

Identification and classification

The waste producers usually possess the best knowledge of the generated waste, as they are aware of the raw materials²¹ used in the production process and the technologies applied. They should be in charge of the proper classification and registration of their waste. If already available, the national classification system should be used. In any case, a basic characterization with the indication of the main physical and chemical properties is necessary. Further information on other hazardous properties such as explosivity, corrosivity, etc. should be provided. If possible, indications for the appropriate waste treatment could already be given (for example methods of stabilization) [57, p. 234].

Two of the main systems for hazardous waste identification are that of the European Union (EU) and that of the US Environmental Protection Agency (US EPA). These systems determine whether a waste is recognized as hazardous or non-hazardous and are based on defining threshold concentrations for the hazardous characteristics. If the waste exhibits hazardous characteristics at a quantity above such thresholds, it is then considered to be hazardous [58, p. 9].

Labelling

As a generator of hazardous waste, you are responsible for assuring that any container used to accumulate hazardous waste is properly labelled in order to meet regulatory requirements and assure the safety of those around you. During storage and transport, it is important that your waste can be easily identified and that containers are labelled with the following information:

- Indication that it is waste
- Contents of the container (where it is a chemical you should use the chemical identity rather than a trade name)

²¹ Safety data sheets (SDSs) are an important information source to determine whether the waste you produce is hazardous.

- Data of the waste generator
- State of the substance (solid, liquid or gas)
- Hazard(s) where applicable
- Emergency contact details [59, p. 4]

Hazardous waste management components

In principle, waste management comprises any step of handling waste from the moment of its generation up to the moment of its final disposal or its re-entering into the product status by means of recycling or recovery. Accordingly, the EU Waste Framework Directive defines waste management as “the collection, transport, recovery and disposal of waste, including the supervision of such operations and the after-care of disposal sites, and including actions taken as a dealer or broker”.

Segregation

It is important that hazardous waste is segregated properly because of the effects it may have on human health or the environment if it is not properly controlled.

You must keep separate:

- Hazardous waste from non-hazardous waste
- Different types of hazardous waste from each other, and
- Hazardous waste from other materials [59, p. 3].

Storage

Hazardous waste should be properly stored on-site. The storage areas should be away from public places in order to prevent any harm to the public or those persons exposed to the waste, and should be adequately dimensioned for the waste quantities to be stored.

The key factors which a company needs to ensure are that waste is:

- Secure
- Contained so that it cannot escape
- Protected from the weather, vehicles (including fork lift trucks), and scavengers and pests [59, p. 4].

It is important to ensure that any container used for waste meets certain minimum requirements. First and foremost, the container and its closure need to be compatible with the contained waste.

For certain wastes, there are additional storage requirements, for example chemicals which can have different properties and have the potential to react dangerously if not properly stored. The Health and Safety Executive, UK, have produced guidance on dealing with chemical storage (HSG 71)²² and the storage of flammable chemicals (HSG 51)²³.

In small and medium enterprises, often only small quantities of hazardous wastes are generated. Therefore, on-site collection and temporary storage is necessary until quantities are large enough for shipment by a licensed hazardous waste transporter.

Hazardous waste should be stored so as to prevent or control accidental releases to air, soil and water resources in a location where [60, p. 48-49]:

- Waste is stored in a manner that prevents the commingling or contact between incompatible wastes, and allows for inspection between containers to monitor leaks or spills. Examples include sufficient space between incompatibles or physical separation such as walls or containment curbs.
- Waste is stored in closed containers away from direct sunlight, wind and rain.

²² Health and Safety Executive, 2009. Chemical warehousing: The storage of packaged dangerous substances. HSG 71

²³ Health and Safety Executive, 1998. The storage of flammable liquids in containers. HSG 51

- Secondary containment systems should be constructed with materials appropriate for the wastes being contained and adequate to prevent loss to the environment.
- Secondary containment is included wherever liquid wastes are stored in volumes greater than 220 litres. The available volume of secondary containment should be at least 110 per cent of the largest storage container, or 25 per cent of the total storage capacity (whichever is greater), in that specific location.
- Adequate ventilation is provided where volatile wastes are stored.

Hazardous waste storage activities should also be subject to special management actions, conducted by employees who have received specific training in handling and storage of hazardous wastes. These activities include [60, p. 49]:

- Providing readily available information on chemical compatibility to employees, including labelling each container to identify its contents
- Limiting access to hazardous waste storage areas to employees who have received proper training
- Clearly identifying (label) and demarcating the area, including documentation of its location on a facility map or site plan
- Conducting periodic inspections of waste storage areas and documenting the findings
- Preparing and implementing spill response and emergency plans to address their accidental release
- Avoiding underground storage tanks and underground piping of hazardous waste

Collection and transportation

On-site and off-site transportation of waste should be conducted so as to prevent or minimize spills, releases and exposures of employees and the public. A licensed waste transporter²⁴ must ensure that hazardous waste is packaged, documented and labelled in compliance with the method of transport used (road, rail, air or sea) [60, p. 49].

Moreover, the transporter must ensure that the emergency response information contained on the manifest is immediately accessible to emergency responders. The transporter regulations do not apply to the on-site transportation of hazardous waste by generators who have their own treatment or disposal facilities, nor to TSD facilities transporting wastes within a facility.

All waste containers designated for off-site shipment should be secured and labelled with the contents and associated hazards, properly loaded on the transport vehicles before leaving the site, and accompanied by a shipping paper (i.e., EU consignment note²⁵ or US hazardous waste manifest²⁶) that describes the load and its associated hazards [60, p. 49]). Completion of the documentation together with proper marking and labelling of containers and vehicles enables police, ambulance, fire and other first responders to react effectively and safely in the event of a spill or other accident involving hazardous waste while in transit.

Information required for consignment notes in the UK including an example can be found in the Guide to Hazardous Waste Regulations for small businesses published by the UK Environment Agency [59, p. 6]. However, local regulations and requirements must be observed.

Treatment and disposal of hazardous wastes

The purpose of treating hazardous waste is to convert it into non-hazardous substances or to stabilize or encapsulate the waste so that it will not migrate and present a hazard when released to the

²⁴ US EPA regulations governing hazardous waste transporters: <http://www.epa.gov/osw/inforesources/pubs/orientat/rom34.pdf>

EU DIRECTIVE 2008/68/EC on the inland transport of dangerous goods:
<http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:260:0013:0059:en:PDF>

²⁵ EC detailed description of consignment note data: <http://ec.europa.eu/transport/rail/interoperability/doc/aeif-annex-a3-en.pdf>

²⁶ US EPA hazardous waste manifest system: <http://www.epa.gov/waste/hazard/transportation/manifest/index.htm>

environment. Treatment methods can be generally classified as chemical, physical, thermal and/or biological.

Some types of waste may be managed properly and legally at company premises (for example in case of reuse). Other types require particular handling and shipment to businesses that are specialized and licensed in storage, recycling, treatment and disposal technologies. It is the responsibility of an enterprise to decide which method of management is best for the facility in terms of future liability, potential adverse environmental impact and cost [60, p. 48].

Selected management approaches should be consistent with the characteristics of the waste and local regulations, and may include one or more of the following [60, p. 48]:

- On-site or off-site biological, chemical or physical treatment of the waste material to render it non-hazardous prior to final disposal
- Treatment or disposal at authorized facilities specially designed to receive the waste. Examples include composting operations for organic non-hazardous wastes, properly designed, licensed and operated landfills or incinerators designed for the respective type of waste, or other methods known to be effective in the safe, final disposal of waste materials such as bioremediation.

In the absence of qualified commercial or government-owned waste disposal operators (taking into consideration proximity and transportation requirements), companies should consider [60, p. 50]:

- Installing on-site waste treatment or recycling processes
- As a final option, constructing facilities that will provide for the environmentally sound, long-term storage of wastes on-site or at an alternative appropriate location until external commercial options become available

The following table shows the main processes for waste treatment and disposal:

Table 3-19: Waste disposal technologies [based on 62, p. 147]

1. Physical treatment processes			2. Chemical treatment processes	3. Biological treatment processes	4. Thermal treatment processes	5. Disposal processes
a. Gas cleaning	b. Liquids-solids separation	c. Removal of specific components	a. Absorption	a. Aerobic systems	a. Incineration	a. Deep-well disposal
i. Mechanical collection	i. Centrifugation	i. Adsorption	b. Chemical oxidation	b. Anaerobic systems	b. Pyrolysis	b. Dilution and dispersal
ii. Electrostatic precipitation	ii. Clarification	ii. Crystallization	c. Chemical precipitation	c. Activated sludge	c. Vitrification	c. Ocean dumping
iii. Fabric filter	iii. Coagulation	iii. Dialysis	d. Chemical reduction	d. Spray irrigation		d. Sanitary landfill
iv. Wet scrubbing	iv. Filtration	iv. Distillation	e. Wet oxidation	e. Tricking filters		e. Land burial
v. Activated carbon adsorption	v. Flocculation	v. Electrodialysis	f. Ion exchange	f. Waste stabilization ponds		
vi. Adsorption	vi. Flotation	vi. Evaporation	g. Neutralization	g. Rotating bio contactors		
	vii. Foaming	vii. Leaching	h. Chemical fixation and solidification			
	viii. Sedimentation	viii. Reverse osmosis	i. Dehalogenation			
	ix. Thickening	ix. Solvent extraction				
		x. Stripping				

Monitoring

Monitoring activities associated with the management of hazardous and non-hazardous waste should include:

- Regular visual inspection of all waste storage and collection areas for evidence of accidental releases and verification that wastes are properly labelled and stored. When significant quantities of hazardous wastes are generated and stored on site, monitoring activities should include:
 - Inspection of vessels for leaks, drips or other indications of loss
 - Identification of cracks, corrosion or damage to tanks, protective equipment or floors
 - Verification of locks, emergency valves and other safety devices for easy operation (lubricating if required and keeping locks and safety equipment in standby position when the area is not occupied)
 - Checking the operability of emergency systems
 - Documenting results of testing for integrity, emissions or monitoring stations (air, soil vapour or groundwater)
 - Documenting any changes to the storage facility and any significant changes in the quantity of materials in storage
- Regular audits of waste segregation and collection practices including tracking of waste generation trends by type and amount of waste generated, preferably by facility departments
- Characterizing waste at the beginning of the generation of a new waste stream, and periodically documenting the characteristics and proper management of the waste, especially hazardous wastes
- Keeping manifests or other records that document the amount of waste generated and its destination
- Periodic auditing of third-party treatment and disposal services including re-use and recycling facilities when significant quantities of hazardous wastes are managed by third parties. Whenever possible, audits should include site visits to the treatment storage and disposal location.

3.9.3 Additional sources of information

Websites

UNEP-Global Partnership on Waste Management (GPWM): provides a guideline platform that deals with different aspects of waste management, including hazardous waste: <http://www.unep.org/gpwm/InformationPlatform/WasteManagementGuidelines/tabid/104478/Default.aspx>

UK Environment Agency: provides information and guidelines that will help you classify your waste (using the List of Waste), identify if it is hazardous waste, and understand the controls that apply to hazardous waste: <http://www.environment-agency.gov.uk/business/topics/waste/32180.aspx>

Website of the European Commission: provides information on EU hazardous waste legislation: http://ec.europa.eu/environment/waste/hazardous_index.htm

Documents

DEFRA (Department for the Environment, Food and Rural Affairs, UK): “Guidance on Applying the Waste Hierarchy to Hazardous Waste” (2011). This guidance is for any business or public body which generates, handles or treats hazardous waste.

GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit) “Manual on industrial hazardous waste management for authorities in low and middle income economies” (2012): gives an overview of key issues related to legal requirements and practical procedures pertaining to the environmentally sound management of hazardous waste, taking into account requirements, recommendations and guidelines supplied by the Basel Convention and OECD, where relevant, and providing provisions and procedures, in particular from the European Union, as model examples.

IFC (International Finance Corporation, World Bank Group): “General EHS Guidelines: Environmental Waste Management” (2007): provides general guidelines for the management of non-hazardous and hazardous waste

EU: “Reference Document on Best Available Techniques for the Waste Treatments Industries” (2006): provides BAT in the waste treatment sector, including generic BAT and BAT for specific types of waste treatments

Environment Agency UK: “Guide to the Hazardous Waste Regulations for Small Businesses” (2013): explains how to determine if your waste is hazardous and what your responsibilities are as a producer of hazardous waste

Blackman, William C. “Basic hazardous waste management”, third edition (2001), Lewis Publishers, CRC Press LLC.

3.10 Energy efficiency and chemicals

Industrial boiler design and operating conditions can have a significant impact on the production of persistent organic pollutants (POPs). Boilers are used for heating water for industrial processing or for domestic and industrial heating but also for producing steam. They can unintentionally form or release dioxins and furans (PCDD/F) or hexachlorobenzene (HCB). It has been demonstrated that it is possible for these compounds to be unintentionally formed during the combustion of fossil fuels. The volumetric concentrations of these pollutants in the emissions from boilers are generally very low. However, the total mass emissions from the boiler sector may be significant because of the scale of fossil fuel combustion in terms of tonnage and distribution. Besides the emission of POPs, the combustion of fossil fuels also forms other types of pollutants like SO₂, NO_x, CO and particulate matter that may have a significant effect on the environment [63].

The unintentional production of POPs compounds during the combustion process follows three general pathways:

- Undestroyed compounds originally present in the fuel
- Gas-phase formation from precursors (for example polyhalogenated phenols, chlorinated aromatic compounds) at temperatures higher than 500°C
- Re-formation of POPs in the cooling of flue gases

Modern industrial boilers are normally identified by the methods of heat transfer utilized.

3.10.1 Heat transfer systems

- **Water-tube boilers:** Heat transfer tubes containing water are directly contacted by hot combustion gases. Commonly used in coal fired boilers but can accommodate almost any combustible fuel including oil, gas, biomass and refuse-derived fuel (RDF).
- **Fire-tube boilers:** Water surrounds tubes through which hot combustion gases are circulated. The application is more common for pulverized coal, gas and oil fired boilers but various types can also burn biomass and RDF. They are generally used for lower pressure applications.
- **Cast-iron boilers:** Cast sections of the boiler contain passages for both water and combustion gas, used for low-pressure steam and hot water production. They are generally oil or gas fired with a smaller number of coal-fired units.



Figure 3-23: Fire-tube boiler (opened) [72]

3.10.2 Fuel type

Various types of fuels such as coal, oil, gas and biomass are used either individually or in combination with energy-containing waste products from other processes for steam and hot water generation in boilers. The type of fuel used depends on fuel availability and process economics.

Heavy fuel oil is still combusted for steam generation and is usually burned in specially designed burners incorporated in the boiler walls. The formation of PCDD/PCDF is favoured during co-combustion when liquid or sludge wastes such as waste oil or used solvents are added to the fuel mix, possibly due to lowered combustion efficiency.



Figure 3-24: Fuel oil operated boilers [72]

Light fuel oil and natural gas are always fired in specially designed burners and are generally unlikely to generate large amounts of PCDD/PCDFs, since both are very high calorific, clean-burning fuels with little ash.

Coal use in less efficient sectors could be a significant source of local emissions. It is acknowledged that the reduction techniques for dusts, SO₂ and NO_x on a flue gas can also reduce or remove PCDD/PCDF. This reduction is inconstant.

The use of **biomass** energy derived from renewable animal and plant sources can contribute to the energy requirements of industrial boilers. Usually the combustion of renewable biomass is less efficient than conventional fossil fuels and it is mostly burnt as a supplement along with feed from a conventional fossil fuel energy source. Potential for POPs emission may be increased by co-firing biomass if the boiler efficiency is not maintained by appropriate system redesign or control.

3.10.3 Emission reduction measures

In order to reduce the emission of POPs from fossil fuel-fired industrial boilers, the three pathways mentioned above must be minimized in the design and operation of the process. This will be effectively achieved by addressing:

- Energy conservation
- Fuel quality
- Combustion conditions
- Installation of most appropriate air pollution control devices

While the low level of precursors necessary to promote the unintentional formation of POPs via gas formation above 500°C occurs in most fuels, attention must be paid to reduce, as much as possible, the unintentional introduction of contaminated fuels, which may promote the formation of POPs. This is especially valid when co-firing fossil fuels with waste material. Other types of pollutants like SO₂ can also excessively occur due to low fuel quality.

The table below shows the scale of the potential firing technique savings achieved by the designated remedial actions. This is only a rough calculation. The actual savings would have to be calculated based on the actual plant and using the current operating profile. The designated values depend on the plant's condition.

Table 3-20: Energy saving potential in different areas of an industrial combustion plant

Loss	Remedy	Energy savings
Flue gas losses	Economizer	3-15%
	Air pre-heater	
	Condensing technology	
Surface losses	Appropriate insulation	0.3-1%
	Lower boiler pressure	
	Combustion air from top of boiler house	
Purging losses	Optimize control circuits	0.2-5%
	Hot standby	
	Set wider turndown ratio of burner	
Boiler scale	Correct feedwater preparation	Up to 10%
	Clean boiler	
	Optimize flue gas temperature	
Water losses	Replace pipes	0.2-1%
	Renew seals	
	Change valves and cocks	
Blowdown losses	Retrofit continuously regulated blowdown	0.5-5%
	Fit blowdown heat exchanger	
	Correctly adjust blowdown valve	
Excess air	Retrofit electronic compound regulator	0.5-1.5%
	Retrofit O ₂ and CO control system	
Plumes of steam	Retrofit vent condenser	0.3-4%
	Retrofit deaerator control unit	
	Retrofit magnetic shut-off valve	

Combustion conditions

To achieve the complete combustion of POPs contained in the fuel, special attention has to be paid to the four cornerstones of high destruction efficiency: **temperature**, **time**, **turbulence** and **excess oxygen**. In this way, precursors are destroyed and soot formation is reduced, allowing fewer possible sites for solid catalysis in the cooling gas effluent. It is generally accepted that a temperature over 900°C and a gas residence time of 2 seconds are sufficient to achieve the complete oxidation of dioxins as long as the gas flow is sufficiently turbulent and excess oxygen is present.

The air-fuel ratio for every firing has to be precisely calculated and adjusted accordingly to obtain the required output. Each level of output or quantity of fuel requires an exact amount of air. A regulator is required to calculate how much air is needed for which quantity of oil and gas. Mechanical regulators are robust, easy to use and have an air curve for all fuels but the mechanical tolerance could result in excess amounts of air being used and might not compensate temperature variations [64].

With electronic compound regulation, a microcontroller adjusts all firing functions individually. For this purpose, each valve and trap has its own actuator which is individually programmed at each load point. This means that different programmes can be used for different fuels. By using precisely adjusted valves and traps, the fuel consumption can be drastically reduced, whilst allowing O₂ and CO regulation.

The different densities of the hot and cold induction air have an effect on the oxygen transfer and may change fuel consumption significantly. Fixed regulation means that a burner set up in winter with little excess air may be operated in summer with an air deficit if the supply is not manually adjusted. A combined O₂/CO regulation always prevents an excess of air within a defined, lower range and equalizes the constant variations between temperature and pressure in the ambient air. It includes a broad regulation range for the O₂ content. In addition, CO occurs as a stop signal. Gases are measured by a lambda wave in the waste gas stream and the measurement signals are used to regulate the amount of air. A lower quantity of excess O₂ therefore results in fuel savings of up to 2 per cent.

Heat recovery

Usually, the waste gas temperature is slightly above the medium temperature when heat is generated at 30-50 K, which represents the lowest threshold at which the waste gas can be cooled inside the boiler. Waste gas temperatures of 250° C or even 400° C downstream of thermal oil heaters therefore occur inside the plant. The residual heat contained in the exhaust gas can be partially recovered through heat exchange by using so-called economizers that preheat the feed water, or through air-to-air heat exchangers that heat the fresh air. Regardless of the type of heat exchanger, a retrofit achieves significant savings if the plant discharges large quantities of waste gas. As a rule of thumb, a 100 K reduction of the waste gas temperature saves 4 per cent of fuel, whatever the operating method.

An **economizer** passes boiler feed water through the waste gas stream at a temperature of 103° C, before it returns to the boiler, causing the temperature to increase from 125° C to 135° C while the waste gas is cooled down. This temperature should not be exceeded in order to avoid the condensation of the waste gas in the chimney, which may cause construction damage or corrosion. If the sulphur concentration in the waste gas is elevated, the temperature must be even higher. In addition, if the waste gases contain dust, the heat exchanger's geometry will have to be adjusted to prevent blockage. Using an economizer has been tested worldwide and it works: the higher the waste gas temperature the longer the full-load operation and the quicker the amortization.

Economizers must not be used, if the boiler contains high-pressure condensates or if thermal oil is used instead of water. In this case, **air-to-air heat exchangers (air pre-heaters)** are used. This type of heat exchanger uses the residual energy of the waste gas to heat the burner's combustion air and can reduce energy costs by over 5 per cent. Usually, however, the burner control has to be reconfigured, if the fuel-air ratio is altered.

If the waste gas is cooled again downstream of the economizer, condensate is formed. In this case, the so-called **condensing technology** can be used to recover condensation heat. It involves a heat exchanger in the waste gas with sufficiently cold surfaces, on which water vapour can condense. The heat exchanger must be made of stainless steel and is connected to a condensate removal system in order to avoid corrosion by the acidic condensate. The waste gas is cooled down to a temperature of 45 to 50°C and fresh water can be heated to approximately 60°C. A 50-per cent condensation of the waste gas may result in 5.5 per cent fuel savings.

Depending on the heat generator, it is also possible to combine all three heat recovery technologies, specifically economizers, condensing technology and air pre-heaters. The table below summarizes the potential energy savings achieved by these three technologies.

Table 3-21: Potential energy savings of different heat recovery technologies

Technology	Medium	Operational area	Potential saving
Economizer	Waste gases/water Boiler supply water pre-heated	Downstream of heat exchanger; for supply water	4-7%
Air-to-air heat exchanger	Waste gas/air Combustion air pre-heated	Downstream of heat exchanger at high temperatures (water tube boilers, thermal oil heaters) or residual heat final phase	4-10% (water tube boilers, thermal oil heater) 0.5-4% (final phase)
Condensing technology	Waste gas/water Prepared water/process water pre-heated	As second heat exchanger downstream of an economizer or air-to-air heat exchanger	4-7%

Blowdown

When vapour is removed from the boiler, salts are concentrated as water is continually added to the boiler. The amount of salt and additives depends greatly on the way the water was previously processed and is lowest in de-ionized supply water. The dissolved salts, particularly sodium hydrogen carbonate, are expelled from the boiler using the blowdown valve, with hot water being discharged along with the accumulated salt. The manual operation of the blowdown valve often results in unwanted water and energy losses, since the salt concentration is not always visible in the water. By continuously measuring the electrical conductance, an undesired high carbonate content of the water can be determined. Coupled with a regulator and an automatic blowdown valve, the conductance, and therefore the salt content in the boiler water, may be kept exactly below a set threshold level and no more water than necessary is discharged.

Using a blowdown cooler, the residual water may then serve to heat up additional water, which then flows from the water processor into the degasser.

These measures discharge cool salt water while heat and expensive supply water remain in circulation and can achieve energy savings of up to 5 per cent.

4 Case studies

In the following selected case studies with findings of assessments in the paints and varnish industry are presented that were elaborated by the National Cleaner Production Centres (NCPC) participating in the present project on *Innovative Approaches for the Sound Management of Chemicals and Chemical Waste*.



CASE STUDY: J & S Ferretería Industrial

PROJECT AIM

The aim of the project *Innovative Approaches for the Sound Management of Chemicals and Chemical Waste* is to facilitate the implementation of innovations in the production and application of chemicals to achieve a reduction in the consumption of chemicals, energy and water; improvements in the safe management of chemicals and risk reduction related to chemical accidents. Resource efficient options and technologies will be addressed as well as replacement of hazardous chemicals by chemicals with lower risk.

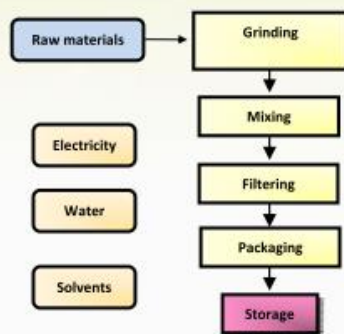
GENERAL COMPANY INFORMATION



Universal Colors products

Company	J & S Ferretería Industrial (Universal Colors) Four Street (Mz D Lt. 26) Urb. Ind. Grimaneza - Callao
Sector	Paint manufacture
Products	Paints and varnishes
Market	National
Workforce	15
Turnover	USD 2,000,000

PRODUCTION



General process flow diagram

Key processes	mixing, homogenizing, grinding
Raw Materials	epoxy resin, epoxy hardener, ammonia, xylene, methyl isobutyl ketone
Energy sources	electricity
Equipment	mixing and grinding machines
Wastes	rags contaminated with solvent and contaminated resin
Wastewater	domestic waste water
Emissions	NO _x (<0.7 µg/m ³), SO ₂ (<0.6 µg/m ³), CO, VOC



Zinc chromate anticorrosive primer

Project focus	Substitution of inhibitor pigment (zinc chromate) with an environmentally friendly pigment for anticorrosive primer products
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INNOVATION ASSESSMENT



Mixing process for zinc chromate primer

PROCESS IMPROVEMENTS



Zinc chromate free product

J&S Ferrería Industrial was approached to conduct an innovation assessment to determine the three basic technical components of increasing material and energy efficiency to produce more products with correspondingly less waste and pollutants, a reduction in toxicity of materials used and safety and risk reduction. Particular focus lied on the innovative solutions in these areas which were generated, implemented, monitored and documented together with the company representative.

Anticorrosive primer manufactured by J&S Ferrería Industrial is used as metallic cover in the industry. The inhibitor pigment, zinc chromate, is considered a carcinogenic compound which affects workers during paint manufacturing and users of the product.

The company developed, with the assistance of the corrosion institute ICP-PUCP, an environmentally friendly anticorrosive pigment which replaced chromate by modified phosphates. The product, whose effectiveness was proven and validated by the corrosion institute, is competitively priced with the current market.

This project eliminated zinc chromate from anticorrosive primers, reduced the time of the manufacturing process and the price is as competitive as before.

BENEFITS



Corrosion test to verify effectiveness of actual product (left) vs. old product (right)

The main goal of the project was the reformulation of the anticorrosive primer with the hazardous pigment to a less hazardous product.

Significant improvements are:

- Elimination of zinc chromate
- Reduction of manufacturing time because of lower grinding time
- Reduction of energy consumption of nearly 80%
- The proportion of new pigments in the paint is only 10%
- Competitive price, the new product costs 1 USD more per gallon

Clean Technology	Environmental/Safety benefits				Economic data	
	Chemical consumption (gallon)		Energy consumption		Costs for the most important raw materials [USD/gallon] old/new	Investment costs for the development of the new product (USD)
	Zinc chromate [% w/gal] old/new	% reduction	Electricity [kWh/gal] old/new	% reduction		
Elimination of zinc chromate	15% / 0%	100 %	0.22 / 0.03	78 %	5.52 / 7.2* *due to higher costs for the new pigments	207,000

COMPANY STATEMENT

The enterprise is committed to ensure the quality of the environment through the reduction and elimination of toxic substances of our paint products.

Luis Figueroa Ramos – Technical Chief of J&S Ferrería Industrial

FURTHER INFORMATION

CER Perú Cleaner Production Centre
 Av. Chorrillos 150 – Chorrillos
 Tel: +51 467-1958 – 467-1802, Fax +51 467 - 1975
 www.cer.org.pe Email: contacto@cer.org.pe



CASE STUDY: J & S Ferreteria Industrial

PROJECT AIM

The aim of the project *Innovative Approaches for the Sound Management of Chemicals and Chemical Waste* is to facilitate the implementation of innovations in the production and application of chemicals to achieve a reduction in the consumption of chemicals, energy and water; improvements in the safe management of chemicals and risk reduction related to chemical accidents. Resource efficient options and technologies will be addressed as well as replacement of hazardous chemicals by chemicals with lower risk.

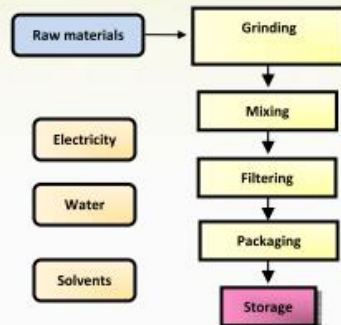
GENERAL COMPANY INFORMATION



Universal Colors products

Company	J & S Ferreteria Industrial (Universal Colors)
	Four Street (Mz D Lt. 26) Urb. Ind. Grimaneza - Callao
Sector	Paint manufacture
Products	Paints and varnishes
Market	National
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Turnover	USD 2,000,000

PRODUCTION



General process flow diagram

Key processes	mixing, homogenizing and grinding
Raw Materials	epoxy resin, epoxy hardener, ammonia, xylene, methyl isobutyl ketone
Energy sources	electricity
Equipment	mixing and grinding machines
Wastes	rags contaminated with solvent and contaminated resin
Wastewater	domestic waste water
Emissions	NO _x (<0.7 µg/m ³), SO ₂ (<0.6 µg/m ³), CO, VOC



Former latex product

Project focus	Reformulation of latex paints for interior painting; reduction of VOC and elimination of ammonia
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INNOVATION ASSESSMENT



Mixing process for latex manufacturing

J&S Ferreteria Industrial was approached to conduct an innovation assessment to determine the three basic technical components of increasing material and energy efficiency to produce more products with correspondingly less waste and pollutants, a reduction in toxicity of materials used and safety and risk reduction. Particular focus lied on the innovative solutions in these areas which were generated, implemented, monitored and documented together with the company representative.

PROCESS IMPROVEMENTS



New product with no ammonia

Latex paints are commonly based on toxic substances among them ammonia. A new formulation, which eliminates ammonia from latex paints, was developed through the development project of the technical manager and with the assistance of the corrosion institute (ICP-PUCP). The new product entailed the substitution of raw materials (resins) and the reduction of coalescent volatile solvents.

The manufacturing of the new product did not result in higher costs for the new process or acquisition of new technologies but required more expensive resins not available in the country.

BENEFITS



Eco friendly product: EcoPrimer

The improvements in the formulation resulted in a low VOC paint and the elimination of toxic solvents without compromising the effectiveness (covering power) and the sales price of the product.

Further significant improvements are:

- Elimination of ammonia
- Reduction of volatile coalescent solvents by 90%
- Competitiveness in national market, sales price of the new product increased by 2 USD per gallon

Clean Technology	Environmental/Safety benefits				Economic data	
	Chemical consumption (gallon)				Costs for the most important raw materials [USD/gallon] old/new	Investment costs for the development of the new product (USD)
	Coalescent solvents (%/gal) (Old/new)	% reduction	Ammonia (%/gallon) (Old/new)	% reduction		
Elimination of toxic paint components	1 % / 0.1 %	90 %	0.1% / 0%	100 %	1.66 / 3.86	2,000

COMPANY STATEMENT

The enterprise is committed to ensure the quality of the environment through the reduction and elimination of toxic substances of our paint products.

Luis Figueroa Ramos – Technical Chief of J&S Ferreteria Industrial

FURTHER INFORMATION

CER Perú Cleaner Production Centre
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 www.cer.org.pe Email: contacto@cer.org.pe



CASE STUDY: CARALZ S.A

PROJECT AIM

The aim of the project *Innovative Approaches for the Sound Management of Chemicals and Chemical Waste* is to facilitate the implementation of innovations in the production and application of chemicals to achieve a reduction in the consumption of chemicals, energy and water; improvements in the safe management of chemicals and risk reduction related to chemical accidents. Resource efficient options and technologies will be addressed as well as replacement of hazardous chemicals by chemicals with lower risk.

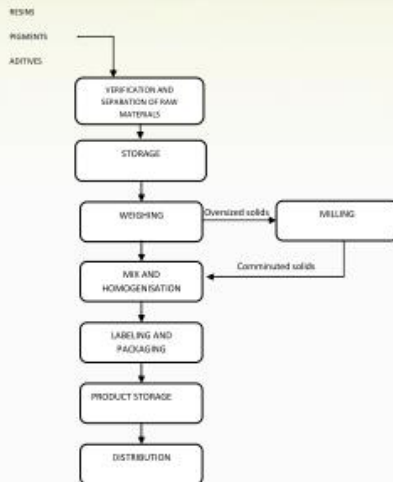
GENERAL COMPANY INFORMATION



Caralz Ltda installations

Company	CARALZ LTDA
	Km 34 motorway Medellin-Bogota
Sector	Paint formulation
Principal Products	Automotive paint, industrial paint and architectural paint
Market	Mainly automotive
Workforce	46 employees

PRODUCTION



Flow Chart automotive paints

Key processes	Storage, mixing and homogenization, labeling and packaging, distribution
Raw Materials	Pigments, resins, solvents
Energy sources	Electricity
Equipment	Mixers, Mills, Dispenser
Wastes	Sludge with hexavalent chromium and lead, contaminated drums, plastic bags contaminated with resin, contaminated rags, kraft paper sacks, contaminated solvents
Wastewater	heavy metals, COD, BOD
Emission	VOC, Particulate emissions

Project focus: Substitution of lead containing pigments

INNOVATION ASSESSMENT



Caralz Ltda installations

Caralz Ltda was approached to conduct an innovation assessment to determine the three basic technical components of increasing material and energy efficiency to produce more products with correspondingly less waste and pollutants, a reduction in toxicity of materials used and safety and risk reduction. Particular focus lied on the innovative solutions in these areas which were generated, implemented, monitored and documented together with the company representative.

PROCESS IMPROVEMENTS



Some pigments used by the company

Traditional yellow pigments at Caralz contain lead. This toxic heavy metal might be taken up by humans by inhalation from the paints and the residues left from manufacturing processes.

To reduce these risks, the company developed a new production line with lead free pigments.

The cost of the new pigments amounts 49 USD/kg.

BENEFITS



Advertising of the unleaded product

Among the main benefits are taken with the new production line are:

- Compliance with international regulations
- Reduction of hazardous waste generated by the company
- Less cost of hazardous waste disposal through waste reduction

Although the new unleaded product is sold on a higher price, the reduced environmental impact and good product properties fully compensate the higher cost.

Clean Technology	Pigment change			
	\$ Pigment with lead/kg	\$ new pigment (unleaded)/kg	\$/Gal product with lead	\$/Gal unleaded product
New production line with unleaded pigments	6.55 USD	49 USD	59,5 USD	142,5 USD

COMPANY STATEMENT

The owner of Caralz Ltda is committed to ensure the quality of products with less chemicals and energy consumption to meet increased market demands and ensure jobs.

FURTHER INFORMATION

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 www.cnpml.org Email: paula.hoyos@cnpml.org



CASE STUDY: CARALZ

PROJECT AIM

The aim of the project *Innovative Approaches for the Sound Management of Chemicals and Chemical Waste* is to facilitate the implementation of innovations in the production and application of chemicals to achieve a reduction in the consumption of chemicals, energy and water; improvements in the safe management of chemicals and risk reduction related to chemical accidents. Resource efficient options and technologies will be addressed as well as replacement of hazardous chemicals by chemicals with lower risk.

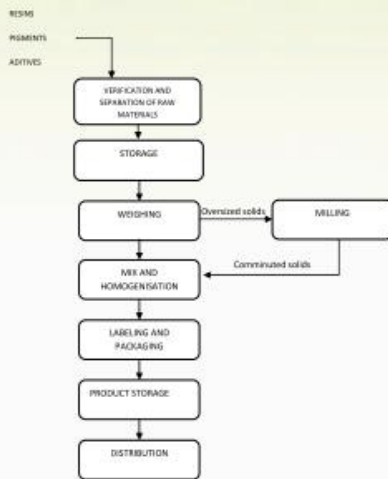
GENERAL COMPANY INFORMATION



Caralz Ltda installations

Company	CARALZ LTDA Km 34 motorway Medellín-Bogota
Sector	Paint formulation
Principal Products	Automotive paint, industrial paint and architectural paint
Market	Mainly automotive
Workforce	46 employees

PRODUCTION



Flow Chart automotive paints

Key processes	Storage, mixing and homogenization, labeling and packaging, distribution
Raw Materials	Pigments, resins, solvents
Energy sources	Electricity
Equipment	Mixers, Mills, Disperser
Wastes	Sludge with hexavalent chromium and lead, contaminated drums, plastic bags contaminated with resin, contaminated rags, kraft paper sacks, contaminated solvents
Wastewater	Heavy metals
Emissions	VOC, Particulate emissions

Project focus: Reduction of chemicals consumption by recovery and reuse of solvents

INNOVATION ASSESSMENT



Caralz Ltda premises

Caralz Ltda was approached to conduct an innovation assessment to determine the three basic technical components of increasing material and energy efficiency to produce more products with correspondingly less waste and pollutants, a reduction in toxicity of materials used and safety and risk reduction. Particular focus lied on the innovative solutions in these areas which were generated, implemented, monitored and documented together with the company representative.

PROCESS IMPROVEMENTS



Distiller of solvents

Solvents are a major chemical input for the company. That is why large quantities are purchased monthly. The solvents are used in manufacturing processes and the cleaning activities. In particular cleaning generates high quantities of solvent waste used for cleaning tools and equipment. The reuse of contaminated solvents does not comply with the quality requirements.

The company is currently buying 35 gallons weekly (1750 gallons per year) which implies an expenditure of approximately 3500 USD/year for the purchase of new solvents. This cost could be reduced by solvent recovery using a new distillation equipment.

BENEFITS



Testing with solvent

The main benefits of the solvent distillation are:

- Reduced purchase of solvents
- Less raw material cost
- Decrease of hazardous waste generated by the company
- Less cost for hazardous waste disposal

Clean Technology	Environmental/Safety benefits		Economic savings			
	Chemical consumption		Cost of solvent / Gal	Saving by solvent recovery (USD/year)	Cost of disposal/Gal	Savings in disposal of solvents (USD/year)
	Buy solvent Gallon / year	Solvent recovered by the distiller (efficiency 90%) Gallon / year				
Purchase of solvent distillation equipment	1750	1575	2 USD	3150	3 USD	4725

COMPANY STATEMENT

The owner of Caralz Ltda is committed to ensure the quality of products with less chemicals and energy consumption to meet increased market demands and ensure jobs.

FURTHER INFORMATION

Cleaner Production Centre
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 Tel: +574 4601777, Fax + 0574 5109000
 www.cnpml.org Email: paula.hoyos@cnpml.org



CASE STUDY: Avery Dennison El Salvador

PROJECT AIM

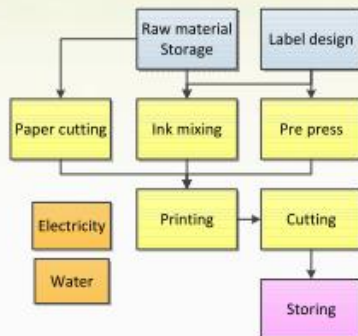
The aim of the project *Innovative Approaches for the Sound Management of Chemicals and Chemical Waste* is to facilitate the implementation of innovations in the production and application of chemicals to achieve a reduction in the consumption of chemicals, energy and water; improvements in the safe management of chemicals and risk reduction related to chemical accidents. Resource efficient options and technologies will be addressed as well as replacement of hazardous chemicals by chemicals with lower risk.

GENERAL COMPANY INFORMATION



Company	Avery Dennison
Address	Zona Franca Internacional, kilómetro 28 1/2, carretera a Comalapa, edificio Multiservicio #1, Olocuilta, SLV
Sector	Paint (ink) formulation and application.
Products	Labels and adhesive labels
Market	Domestic and export (recognized clothing brands)
Workforce	250

PRODUCTION



Avery Dennison SLV Process flow diagram



Production Line Avery Dennison SLV

Key processes	Mixing, pre-press (photoengraving), printing
Raw Materials	Inks, paper, solvent (IPA)
Energy sources	Electricity
Equipment	Mixing machines, photoengraving machines, printers, winding machine, weaving machine
Wastes	Used inks, wipers with solvent, paper
Wastewater	Water used on heat transfer, water for washing
Emissions	VOC, heat loss, CO ₂ due to energy consumption

Project focus	Solvent consumption, material losses and ink wastes, water consumption, energy efficiency and chemical handling
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INNOVATION ASSESSMENT

Improper handling of wastes in production area

Avery Dennison was approached to conduct an innovation assessment to determine the three basic technical components of increasing material and energy efficiency to produce more products with correspondingly less waste and pollutants, a reduction in toxicity of materials used and safety and risk reduction. Particular focus lied on the innovative solutions in these areas which were generated, implemented, monitored and documented together with the company representative.

PROCESS IMPROVEMENTS

Safe handling of wastes in production area

Improper handling of certain wastes during production like ink wastes and wipers was identified. They are placed in bins located on all the production area. Also in the heat transfer area ventilation systems are limited. This generates a significant VOC load in the production area.

The company installed air extraction systems in the heat transfer area and implemented good housekeeping measures as e.g. appropriate covers of the waste bins.

BENEFITS

The implementation of the air extraction system substantially improved the air quality in the production area by reducing the VOC load in the air. This resulted in improved occupational health conditions with benefits for workers, especially those in the heat transfer area.

The company has also implemented recycling of around 76 gallons of Cyclosol per month in pre-press and installed a treatment plant for the wastewater of the process. The system treats a monthly average of 22,560 gallons (85,728 liters) and finally with the present assessment the lighting was improved with fluorescents of 32 W instead of 40 W.

Clean Technology	Environmental/Safety benefits				Economic savings		
	Chemical consumption		Energy consumption		Total Savings [USD/yr]	Investment [USD]	Simple payback [year]
	ton/ton product (Old/new)	% reduction	kWh/year	% reduction			
Air extraction system for Heat Transfer Area	-	Up to 20% VOC in air	-	-	Savings due to non-productive time	1,000	-
Lighting	-	-	17,067 kWh/year	39	\$ 3,108	\$ 2,549	0.8

COMPANY STATEMENT

At Avery Dennison, we strive for reduced environmental impact of our operations and products. In our manufacturing facilities, we focus on energy efficiency, reduction of greenhouse gas emissions, materials, water and waste and are open to continual improvement.

Ivan Menendez, Environmental Management

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5 Supporting policies

The implementation of innovative solutions for the sound management of chemicals and chemical waste in the private sector is frequently hindered due to technical, financial, organizational and also political reasons. Thus, the creation of an enabling environment with stimulating policies helping overcome barriers is essential for enterprises.

The supplementation of national policy instruments on regional level considering local circumstances might be advantageous. For example, a national support program for energy efficient manufacturing processes might be linked with cantonal subsidies for renewable energy use and information-based instruments. In general following instruments facilitating the implementation of innovative process optimization measures in industry can be differentiated. A mix of these instruments proved to be beneficial:

Market based instruments: they internalize the environmental cost i.e. the polluter pays and take into account the «hidden» cost of production and consumption. For instance, a VOC tax compensates for the environmental cost of ozone formation. Market based instruments also lead to technology innovation such as VOC free products (paints, varnishes etc.) or waste gas burners.

Regulatory instruments: command and control instruments typically form the basis of environmental policy frameworks and should be flexible. In Switzerland, for example, the handling of synthetic refrigerants (HFC) is regulated, restricted to trained personnel and the re-use of GHG refrigerants is promoted. However, the substitution of HFC with environmentally sound and harmless natural refrigerants based on modern technologies is not facilitated at all, showing the one-sided approach of this instrument.

Voluntary agreements: they encourage businesses to improve their resource and energy efficiency beyond regulatory measures. The use of voluntary agreements in parallel with regulations, for instance CO₂ legislation, is most useful. In some countries, an agreement between businesses and the government for reduction of GHG emissions through energy efficiency is possible. This might lead to more proactive behaviour and a shift from end-of-pipe thinking to increased efficiency.

Monitoring: compliance monitoring with relevant indicators is crucial to detect violations and provide evidence to support enforcement actions. Second monitoring allows for assessing whether policies have been effective over the long-term. In some European countries, regular monitoring inspections by parties contracted by the government are conducted for waste water pollution and GHG emissions in industries.

Education: training and outreach are relevant for replication of resource efficiency in industry. For instance, through the resource efficient and cleaner production (RECP) program of UNIDO (see <http://www.unido.org/cp.html>) hundreds of workers were trained on industrial process optimization basics and subsequent train-the-trainers programs on RECP created the basis for further outreach in the countries involved.

Overlapping instruments: some types of instruments overlap and can hamper each other. For example, the enforcement of a CO₂-regulation can lead to a switch from fossil fuel to electricity consumption for heating. Electricity however is to be reduced as well and regulated too (e.g. through the national energy law). A coordinated approach is needed to ensure policy coherence.

In the following sections, supporting policies and instruments are summarized for the countries involved in the UNIDO initiative for innovative approaches for the sound management of chemicals and chemical waste.

5.1 Market-based instruments to promote efficient technologies and preventive environmental practices

Market-based instruments aim at addressing the market failure linked to environmental externalities by changing the economic conditions. Incentives or disincentives are created to put forward or repressing specific behaviours. For instance, prompting businesses to internalize costs induced by their polluting activities (e.g. taxation, non-compliance fines, etc.) or creating property rights (e.g. tradable pollution permits) are two economic instruments. Other market-based instruments can be used to stimulate the use of efficient technologies and preventive environmental practices, they include [65]:

- Grants, subsidies and financial assistance (e.g. National Environmental Fund in Colombia, Subsidy for Technological Conversion to avoid the use of CFC's in Chile)
- Marketable permits
- Deposits and product charges
- Harmful subsidy removal
- Reduction in taxes, duties and fees
- Targeted technical assistance
- Liability rules (firms are held responsible for the environmental damage they cause. This often leads to firms minimizing their risks and taking preventive measures.)

Because market-based instruments act as cost-effective pollution control measures, they have shown to be more economically efficient than just regulatory instruments in reaching pollution reduction goals. They allow a greater flexibility in the choice of technology and prevention strategy and may also provide the government with a source of revenue. The latter can, for instance, be used to support other environmental initiatives enhancing the sustainable development of the country. Before introducing economical instruments, the government should carefully analyze the impact of each instrument on the society and the economy. Indeed, subsidies may be used to make local industries more competitive, which may lead to reduced energy prices and therefore increases in energy consumption, shortages and pollutions.

El Salvador - Market-based instruments

El Salvador has set a market incentive, known as the “**Green Seal**”, to foster the sustainable and efficient use of natural resources and to promote processes and activities preventing the contamination of the environment. The seal was born as an instrument of differentiation for the goods and services produced in an eco-efficient way, as well as for those who are exported to international markets.

El Salvador also has a **Tax incentive law** for the promotion of renewable energies in electricity generation. This law promotes the realization of investment projects based on the use of renewable energy through the use of hydraulic, geothermal, wind and solar resources, as well as the biomass for power generation.

The benefits and tax incentives of this law on electricity generation projects are:

- Projects up to 10 MW: exemption from income tax for a period of ten (10) years
- Projects between 10 and 20 (MW): exemption from income tax for a period of five (5) years
- Projects up to 20 MW: exemption from payment of Customs Duties on machinery, equipment, materials and supplies imports during the first ten (10) years.
- Total exemption from payment of all tax revenues directly from the sale of "Certified Emission Reductions" (CERs) under the Clean Development Mechanism (CDM) or similar carbon markets.

Colombian water quality policy and impacts on water quality

The Colombian water quality regulation is composed of 5 key elements [23]:

- **Registration and permitting:** Any discharger of liquid waste is required to obtain a discharge permit from the appropriate authority.
- **Discharge standards:** Discharge standards regulate the discharges of liquid waste in terms of location and quantity. None of these standards are industry-specific and firms may be inspected at any time to sample effluents and inspect equipment.
- **Licensing :** Prior to construction, facilities that will discharge liquid effluents are required to conduct an environmental impact assessment and hold a public hearing in order to obtain a licence from the environmental authorities.
- **Discharge fees:** Between 1997 and 2002, all water uses discharging liquid effluents in lakes and rivers are obliged to pay a monthly fee per unit of BOD and TSS discharged. Annual targets are set for the total quantity of BOD and TSS discharged into the same water basin, by all the sources. If these targets are not met, the fees paid by the individual facilities are increased, every six months, by a factor of 0.5.
- **Quality standard:** They specify in considerable details, for each type of use, the maximum permissible levels of pollutants.

Colombia's water quality regulation strategy and especially the discharge fee program showed a significant and positive impact on the water quality, as pollution loads dropped dramatically. Indeed, according to a quality evaluation realized in 2002, the implementation of discharge fees reduced the total BOD discharge by 27% and total TSS discharges by 45% between 1997 and 2002.

5.2 Optimization of the use of natural resources and raw materials, minimization of emissions

The optimization of the use of natural resources and raw materials protects the environment but also provides sustainable economic and business practices. One way of optimizing the use of resources is, for instance, by minimizing waste production. By setting objectives, defining and implementing resource optimization and waste reduction strategies, companies are able to:

- gain efficiency in production practices by achieving greater output of product per unit input of natural resources and raw materials.
- improve the financial performance of the firm by using more efficient processes reducing the raw material and natural resource input needed and therefore the related costs.
- enhance the firm's public image, as the environmental impact of a company and willingness to protect the environment are important factors in its overall reputation.
- improve the quality of products produced by introducing new innovation and technological practices.
- meet targets set by environmental regulations, policies and standards. An environmentally responsible firm reduces its harmful emissions and impacts.

In general, Governments and International Organizations (e.g. ISO – International Organization for Standardization) provide regulatory frameworks and guidelines to herd companies towards a more sustainable development. Hereunder, examples of how different countries promote a more sustainable development country-wide are presented.

Egypt

The Government of Egypt has set a strategy to implement a number of policies up to year 2022 to diversify the energy resources and rationalize the energy needs of different activities without hindering the development plans. In April 10th, 2007, the Supreme Energy Council in Egypt adopted a resolution on an ambitious plan aiming at increasing the contribution of renewable energy to reach 20% of total energy generated in 2020 (8% hydro & 12% wind). This target will be achieved by private sector participation in financing, building, owning and operating wind farms in Egypt. By 2020, a total installed wind energy capacity of 7200 MW producing about 31 billion kWh yearly should be reached. The later should result in an annual fuel saving of about seven million tons of oil equivalent and 17 million tons CO₂ emissions reduction.

Colombia

Rates of water use, as well rates for the use of other natural resources, are indirect signals to producers to promote the rational use of these resources. Pollution fees are also a strong signal to firms that an improvement in the firm's pollutant release should be taken into account. Other voluntary mechanisms contribute to reaching these goals especially in Colombian firms:

- environmental management systems in firms
- clean production programs
- eco-labels
- sustainable procurement
- efficiency programs for the use and conservation of water
- clean energy programs
- post-consumer and chemicals management (SAICM / OECD programs).

Morocco

To reduce the emissions of greenhouse gases, the Moroccan energy program will invest an estimated \$18.95 Billion by 2020 and will create about 50,000 jobs. It predicts that, by 2020, electrical power produced by renewable energy (solar, wind, and hydraulic) will account for 42% of the total power produced. The main objectives of this strategy are to:

- decrease the energy dependence
- preserve the Environment
- limit greenhouse gases emissions
- fight against climate change

5.3 Reward for good environmental performance and practices

Rewards for good environmental performance and practices are an innovative way to raise awareness about cleaner production at a company, industry and national level.

El Salvador award programs

El Salvador, has set up a National Environmental Award which is one of the incentives of the State to promote Environmental Management. For this award, the ministry has defined several categories and one of them (Award for the Business Effort) concern private sector companies having carried out environmental restructuring in their processes. The winners receive a medal and/or a honourable mention. According to information provided by the Ministry, during the period 1999-2007, 163 awards and honourable mentions have been given, winners for each of the existing categories. For the category of Business Effort, 12 awards have been granted for the same period.

The Cleaner Production Award is a strategy that MARN, the NCPC and the Central American Commission on Environment and Development (CCAD) have been promoting to the private sector to encourage and reward the companies implementing Cleaner Production as a tool for improving environmental performance and increased competitiveness.

The Energy Efficiency Award is a strategy that the Energy National Council and 21 organizations, including the National Cleaner Production Centre (NCPC) El Salvador, have been promoting to the private sector to encourage and reward the companies implementing Energy Efficiency as a tool for increasing competitiveness. This award was created by the program “El Salvador is saving Energy”.

5.4 Minimization of practices leading to the exclusive use of end-of-pipe technologies

Environmental quality has often been built on regulation and authority control with specific targets and demands imposed by authorities on industries with very little flexibility in regards to reaching these requirements [66]. Such governmental control improved the environmental conditions but also has some drawbacks, such as encouraging the use of end-of-pipe technologies. Several environmental policy instruments, such as tax write-offs, financial support for environmental measures also tend to sometimes support end-of-pipe measures and therefore work against the environmental preventive and cleaner production approach [65].

End-of-pipe technologies are generally used to control the pollution rather than to prevent the pollution from happening. This approach most often comes down to just fulfilling legal prescriptions and typically include solutions like reduction of waste and emissions through treatment units and filters. They generally also lead to higher additional costs compared to preventive and integrated solutions.

Pollution prevention and cleaner production approaches tackles the environmental problems at all levels and all fields. Prevention of waste and emissions are made at the source and the environmental protection is an integral part of process engineering. Environmental innovations are developed within the company and make environmental protection a permanent challenge. Moreover, prevention measures often help reduce costs by optimizing the material and resources consumption.

More recently, many authorities have developed a negotiated compliance approach to build cooperation strategies between the regulators and the regulated (companies, industries, etc.) to, for instance, set and enforce standards and promote an open exchange of information [66]. For example, the authorities might define the targets, but the means of reaching these targets are left to the hands of the companies [66]. This more flexible approach enables the adoption of innovative and preventive technologies.

In Colombia for example, environmental preventive strategies are promoted in the productive general sectors through the Colombian politics of sustainable production and consumption.

Morocco – National program for the Prevention of the Industrial Pollution (PNPPI)

In Morocco, the PNPPI allows harmonization and planning of actions that the Administration and the private sector must achieve in order to prevent pollution. It promotes and implements prevention methods by focusing on the reduction of emissions and waste and on the compliance with environmental laws and regulations.

The specific objectives of the program are:

- diagnosis of the current status, technical, institutional and regulatory framework for the prevention and fight against various forms of industrial pollution
- identification of priority actions to be implemented
- development of terms of reference for studies to be carried

5.5 Industry lead initiatives

The various industry sectors in the economy have very different environmental impacts. The System of Environmental and Economic Accounts (SEEA), an international standard developed within the UN system is used to assess the environmental impact of the different industries in a country and helps in identifying the domains on which the environmental policies should be focused on.

In Peru, illegal gold mining has been identified as a major issue in terms of environmental impact and pollution. Indeed, illegal gold mining lead to high mercury and lead contamination in the Peruvian rainforest. The Peruvian Ministry of Environment has formalized a program to address this environmental issue.

Peru – Chemical industry lead initiatives

In the chemical industry, different projects and technical committees aim to improve and develop a sustainable formulation, production and use of chemical substances. The following programs and committees are managed by the Peruvian Ministry of Environment:

SAICM (Strategic Approach to International Chemicals Management)

The objective of SAICM is to strengthen the institutional capacities, regulations and techniques for managing chemicals in Peru. One output of this project was a toolkit on chemical management. The project was executed by the Centro de Ecoeficiencia y Responsabilidad Social (CER) and Ministry of Health with support of UNIDO during 2009-2011.

"Technical Group for Chemicals" (GRUPO TECNICO DE SUSTANCIAS QUIMICAS)

In 2002, the Chemicals Technical Group (GTSQ) was formed. It is responsible for coordinating integrated actions on chemicals and implementing the Stockholm Convention (Convention on persistent Organic Pollutants), the Rotterdam Convention (Rotterdam Convention on the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade), and the Basel Convention (Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal).

5.6 Regulatory instruments: command and control for environmental protection and safety

Regulatory instruments are used to set a legal framework controlling the environmental impacts of the industries by determining prohibited /allowed behaviours and how to carry out certain environmentally risky activities. Public authorities usually set environmental standards and goals, and then inspect, monitor and punish transgressions with legal sanctions. A sound legal framework promoting environmental protection and safety is generally achieved when [23]:

- the public and private sector cooperate in the elaboration of environmental policies and regulation
- the regulatory framework promotes continuous innovation by not specifying any particular technology
- the innovation resulting from the regulation is decided by the industry and not the regulatory entity
- environmental regulation does not promote end-of-pipe solutions, but promotes source reduction solutions
- low levels of compliance with the standards are not accepted
- incentives are created for the private sector, etc.

Examples of regulatory instruments for the environmental protection and safety, for instance include [65]:

- environmental norms and regulations
- product bans and trade restrictions (cadmium, pesticides, CFC's)
- raw materials depletion quota (forestry law in Costa Rica, prohibiting exports of unprocessed timber)
- facility operation standards / permits
- liability assignment

El Salvador – Environmental regulatory instruments

El Salvador has a Cleaner Production Policy [June 9, 2004] which's main objective is to incorporate ecological efficiency and effectiveness in the environmental performance and competitiveness of the companies, minimizing pollution by the implementation of preventive actions in services, technologies and production processes.

During the governmental program called "País Seguro" (2004-2009), an environmental strategy was established and consisted in the establishment of voluntary agreements for cleaner production between companies and the Ministry of Environment and Natural Resources (MARN in Spanish), to gradually restructure production processes into cleaner processes.

Voluntary Agreements for Cleaner Production (AVPL) are instruments of the environmental policy, based on an agreement between the private sector and the competent public administration, which is legally binding seeks to achieve specific environmental objectives and competitiveness.

Egypt –Environmental policy framework

The environmental policy of the Government of Egypt seeks to achieve environmental protection through the establishment of proper institutional, economic, legislative and technical frameworks at the local, regional, national and international levels. This is expressed through the seven directives of the policy statement of the Minister of State for Environmental Affairs (MSEA):

1. Strengthening partnerships at the national level
2. Supporting bilateral and international partnerships in the environmental fields
3. Enforcing Law 4 of 1994 and Law 9 of 2009 for the protection of the environment, and Law 102 of 1983 for Natural Protectorates and all other environmental legislation
4. Supporting institutional strengthening and capacity building for the Egyptian Environmental Affairs Agency (EEAA) and Environmental Management Units (EMU's) of the governorates
5. Supporting Integrated Environmental Management Systems
6. Integrate the use of market-based instruments in the field of environmental protection
7. Transfer and adaptation of environmentally friendly technologies

Within the national environmental policy framework, an Egyptian Environmental Policy Program has been initiated in 1999 with support from the United States Agency for International Development. Through this program, the Government of Egypt implemented its priority environmental policy objectives and measures, through institutional and regulatory reforms, with a focus on a number of areas. These included economic and institutional constraints, cleaner and more efficient energy use, reduced air pollution, improved solid waste management, sustainable tourism, as well as nature conservation.

Within this policy framework, institutional and regulatory reforms are carried out, aiming at the implementation of national environmental policy objectives and measures. The implementation of the environmental policies of the Government of Egypt, as expressed by the policy framework and directives of the MSEA, is carried out with four main principles underlying environmental management and protection initiatives:

1. Strengthening the Integrative Capacity of Central and Local Government
2. Strengthening of Public - Private Partnerships
3. Partnerships with Environmental Non-Governmental Organization
4. The Integration of Gender Issues in Environmental Policies and Programs

6 Funding of innovations

The lack of attractive financial conditions is in many countries a barrier for widespread investments in new technologies in companies, thus also limiting the success of clean, innovative and environmentally sound technology. That is why numerous alternative finance instruments were developed in the past that facilitate industrial investments. In the following, selected instruments are presented as examples in countries within the scope of the present UNIDO project.

6.1 Funding in Peru

6.1.1 Green Credit Trust Fund

The Green Credit Trust Fund (GCTF) was started in 2004, in Peru by the SECO (State Secretariat for Economic Affairs). It is oriented towards supporting sustainable industrial production initiatives in small and medium enterprises (SMEs). The GCTF supports projects related to eco-efficiency and technological reconversion up to a maximum amount of US\$1 million worth of credit. To benefit from the fund, the enterprise must seek to improve its processes through green technologies. Projects that only aim to fulfil legal requirements are not supported by the credit fund.

To qualify for the GCTF, the enterprise must be registered in Peru, have a maximum of 25% foreign capital and be legally independent from any international organization. The GCTF is available for manufacture companies but SMEs in this sector must not own more than US\$ 8.5 million worth of fixed assets and must not employ more than 500 employees.

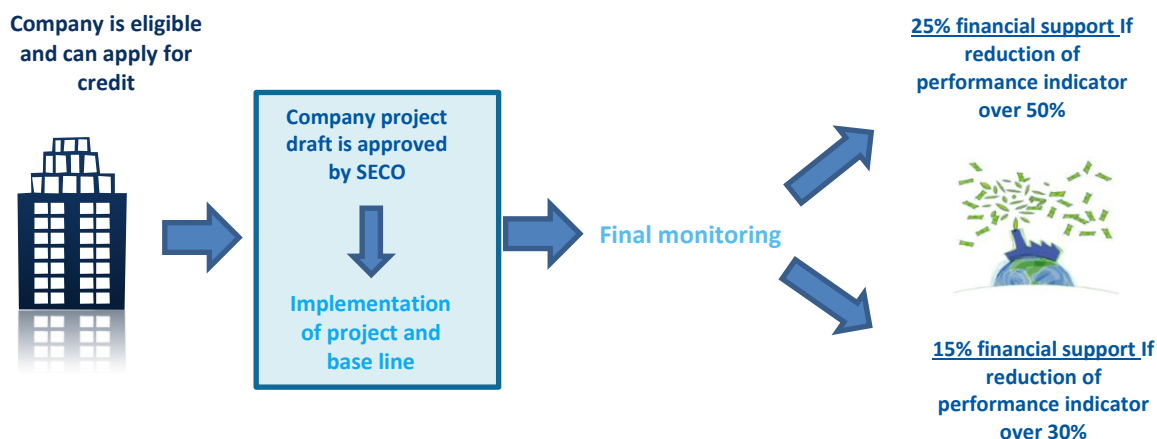
The company first applies for the credit through one of three different intermediary financing institutions (Banco de Crédito del Perú, Interbank and Scotiabank del Perú). Then, the enterprise selects environmental indicators, in consultation with the Peruvian NCPC. Next, an evaluation of whether the new technology will improve the production and reduce the environmental impact of the company is realized. Once the new technology is installed, the indicators are monitored and a report based on the improvements is sent to SECO.

SECO can also provide a guarantee of 50% if required. If the report shows significant improvement of the enterprise's environmental performance, the company receives a reimbursement from SECO.

The reimbursement levels are based on the credit amount or the investment amount, whichever the smaller of the two. The levels are the following:

- 15% reimbursement for 30% worth of environmental improvement.
- 25% reimbursement for 50% worth of environmental improvement.

There are no intermediate levels for the reimbursement.



Since the beginning of the initiative 17 projects have been approved, with a total amount of more than US\$ 4.3 million.

The GCTF concept has proven to be operational. The success is embedded in combining a financial instrument with SED (Sustainable Enterprise Development) centres which have extensive environmental know-how (e.g. in Peru Centro de Ecoeficiencia y Responsabilidad Social (CER)). With the GCTF, no direct interference in finance markets occur, which allows banks to assume their role as agents to analyze the creditworthiness of investments.

Most of the investments prove to be win-win solutions improving the economic aspects as well as reducing the environmental impacts of the companies. Some projects even improve social aspects thus clearly demonstrating the potential of ESTs (Environmentally Sound Technology). With the GCTF, SED centres get access to clients which potentially have projects related to clean production.

6.2 Funding in El Salvador

6.2.1 FONDEPRO

The productive development fund (Fondo de Desarrollo Productivo, FONDEPRO) is an incentive created to promote the development of quality, productivity, innovation, the adoption and implementation of technological improvements leading to cleaner production processes. The fund supports the competitive strengthening of small and medium enterprises by co-financing up to 60% of the total cost of a project or timely initiative.

The fund has 2 co-financing models:

- Fast track model – support of up to US\$ 15,000 for a project focused on a specific activity
- support of up to US\$ 100,000 for a project combining multiple activities

Enterprises must not have annual sales greater than US\$ 7 million, and must be located in El Salvador.

From 2002 to 2008, 718 projects have been supported through the Fast track model, which represents a placement of more than US\$ 1.3 million.

6.2.2 BANDESAL-KFW Environmental Conversion Line

The BANDESAL (El Salvador's Bank for Development) contracted with KFW (Germany) a 3 phases credit line for the environmental conversion of companies. For the first phase, from 2007 to 2010, US\$ 10 million were released, with US\$ 500,000 non-refundable and allocated for technical assistance on environmental projects. For the second (2011 - 2013) and third phases, respectively US\$ 27 million and US\$ 50 million were released.

The main objectives of the program are to contribute to the reduction of the environmental pollution, to promote the efficient use of natural resources by small and medium enterprises and to deepen the financial system by establishing long term instruments for environmental investments for companies located in El Salvador. This program supports entrepreneurs willing to invest in more efficient and environmentally friendly production processes. For an environmental project, the credit limit is set to US\$ 500,000. For a project concerning renewable energies, a credit of maximum US\$ 4 million can be provided (projects of more than US\$ 500,000 require the permission of KFW). The credit finances up to 80% of the value of the investment and has a fixed yearly interest rate of 3.6% for the life of the loan.

Since 2010, the credit line has helped 28 small and medium size companies, with the technical support from NCPC.

The benefits obtained in these 28 companies are, in average, the following:

- energy consumption reduction of 6.7%
-

- fuel oil reduction of 8.4%
- savings of US\$ 1.1 million per year
- investment of US\$ 1.3 million
- CO₂ emissions avoided: 2'300 ton per year

6.3 Funding in Egypt

6.3.1 Private Public Sector Industry project

The Private Public Sector Industry (PPSI) project concerns the protection of the environment by contributing to the reduction of industrial environmental pollution. PPSI focuses on private and public industrial establishments in Upper Egypt and the Delta and operated from 2008-2012. PPSI was implemented by the Egyptian Environmental Affairs Agency and supported by KfW under the German Financial cooperation with Egypt.

Grants covering 20-30% of the pollution abatement investment costs, with a maximum of about US\$ 1 Million, were provided for eligible sub-projects. Preferential treatment applied to SME's (companies with a turnover less than US\$ 2.8 Million) and at least 30% of the investment funds were allocated for SMEs. The PPSI's second stage ended in 2012. The third stage has not started yet.

6.3.2 Environmental Compliance Office Revolving Fund Program

The Environmental Compliance Office (ECO) was set up in 2002 by the Egyptian Government and DANIDA (Danish International Development Agency) to assist in "Achieving Compliance in Industry" (ACI). A cooperation agreement was signed in February 2005 between the Egyptian Environmental Affairs Agency (EEAA), the Federation of Egyptian Industries (FEI) and the National Bank of Egypt (NBE) for the purpose of operating the ECO revolving fund to invest in new equipment.

DANIDA provided funds equivalent more than US\$ 11 million to be allocated within the industrial sector to support initiatives aiming at abating pollution, encouraging safe working conditions and ensuring environmental legislative compliance. The revolving fund provided enterprises with the opportunity to make economic benefits and ensure proper compliance with environmental laws.

Small and medium size enterprises being members of the FEI are eligible to apply.

Loans can reach up to US\$ 420,000 per enterprise with a 2.5% interest rate per year. Loans are repaid over 5 years and funds are reused for financing new Cleaner Production initiatives in other enterprises.

6.4 Funding in Morocco

6.4.1 National Fund for Environment (FNE)

The National Fund for Environment (FNE) is a financial incentive instrument established in 2004 for the protection and valorisation of the environment. This fund aims at:

- funding programs for domestic and industrial water treatment ;
 - financing solid waste management programs ;
 - financing pilot projects for the environment.
-

6.4.2 Fund for Industrial Depollution

The FODEP promotes the environmental upgrading through technical and financial support of industrial companies.

The subsidy covers up to 40% of the investment, with a maximum of US\$ 625,000.

6.4.3 Voluntary Mechanism of Industrial Wastewater Treatment

This program is funded by the Moroccan State and aims at encouraging industrial companies to invest in waste water treatment processes.

Industrial volunteers can benefit from a subsidy covering up to 40% of the investment cost, with a maximum amount of US\$ 625,000 for individual projects and US\$ 1.25 million for collective projects.

6.4.4 Business Advisory Service program

Launched by the European Bank for Reconstruction and Development (EBRD) this program aims at developing the expertise and local consultancy through technical and financial support to consulting assignments. The financial support covers 50% to 75% of the mission's expenses. The Moroccan companies with a turnover of less than US\$ 68.2 million can benefit from this program. Beneficiaries can be supported for the realisation of:

- Technical studies: planning / architectural design, space optimization, IT infrastructure design, selection of machinery and equipment, installation, training ;
 - Quality Management system & Certification: ISO 9000, Hazard Analysis and Critical Control Point (HACCP) ;
 - Energy efficiency and environmental impact reduction: energy audit, mechanism for a clean growth, renewable energy, environmental impact assessment, ISO 14'000 implementation.
-

7 Where do I find support?

The identification and implementation of innovative solutions and alternatives for chemicals and chemical wastes management require extensive know-how about logistic processes, technical requirements, optimization techniques, norms and legal requirements. If a thorough analysis of possible innovations cannot completely be realized within the company by a competent and experienced team, the participation of external experts is highly recommended.

For assistance on innovative chemical solutions, the National Cleaner Production Center (NCPC) program offers services such as RECP assessments on energy and resource efficiency, technology gap assessments and generation of process optimization measures.

NCPC representatives in the five countries involved in the *Innovative Approaches for the Sound Management of Chemicals and Chemical Waste* project can be reached at:

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Further information and contacts can also be found on the UNIDO NCPC website at www.unido.org.

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24. UNIDO Sector Study: Potentials for Chemical leasing in selected cleaning operations, prepared by BiPRO GmbH, Germany (2015)
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27. European Commission, Directive 96/82/EC (Seveso II)
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29. UNEP: Responsible Production Booklet – A Framework for Chemical Hazard Management for Small and Medium Sized Enterprises (2009)
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34. TNO: TNO Purple Book, The Netherlands (1999)
35. ISSA: Maintenance and Changes in Plants with High Safety Requirements: Practical Guidance (2007)
36. US-EPA: General Risk Management Program Guidance, Chapter 7, USA (2004)
37. UNEP: Flexible Framework for Addressing Chemical Accident Prevention and Preparedness (2010)
38. UNECE (United Nations Economic Commission for Europe), GHS (2013)
39. UNEP: Responsible Production Guidance and Toolkit (2009)
40. GIZ: Chemical Management Guide for Small and Medium Sized Enterprises, Germany (2007)
41. Health and Safety Authority: Your steps to chemical safety, A guide for small business, Republic of Ireland (undated)
42. Duke University, Occupational and Environmental Safety Office: Safe use of chemicals, USA
43. Sicherheitsinstitut: Lagerung gefährlicher Stoffe, Leitfaden für die Praxis, überarbeitete Auflage, Switzerland (2011)
44. Vereinigung Kantonaler Feuerversicherung: Directive de protection incendie, liquides inflammables, Switzerland (2003)
45. United Nations: Globally Harmonized System of Classification and Labelling of Chemicals (GHS) (2003, last revision 2013)
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47. United Nations, European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) (1957, last revision 2013)
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50. Usine Nouvelle : Bacs de rétention en plastique, France (2013)
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68. IPTS: Chemical Product Services in the European Union, SAFECEM
69. Suva: Bouteilles à gaz – Entrepôts, rampes, systèmes de distribution de gaz, Switzerland (2007)
70. Sicherheitsinstitut: Lagerung gefährlicher Stoffe, Leitfaden für die Praxis, Überarbeitete Auflage 2011, Switzerland, (2011)
71. VKF/AEAI: Directive protection incendie, liquides inflammables, Switzerland, (2003)

72. CSD Engineers, Switzerland (2015)
73. UNIDO, Environment branch, Vienna (2015)
74. ISSPPRO, Germany (2015)

Appendices

Appendix 1: Suppliers for solvent distillation equipment

Table A1-1: Suppliers for solvent distillation equipment. The table was issued from the Minnesota Technical Assistance Program [based on 12].

Company	Address	Specification
CBG Biotech Columbus, OH 800/941-9484		8 sizes: 2 to 40 gallons, UL listed, air cooled, one model designed for formalin recycling.
CB Mills Gurnee, IL 800/522-7343	George C. Brandt Company St. Paul, MN 651/636-6500 800/999-7053	7 sizes: 15 to 250 gallons, explosion proof, fractionation, scraped surface stills, vacuum.
Chem Champ Ottawa, Ontario 613/594-3337	Envirosota Edina, MN 952/929-2670 Onsite Recycling Services St. Paul, MN 651/247-7414	2 sizes: 5 and 18 gallons, CSA and ETL approved, explosion proof, liner. Onsite Recycling Services also can arrange equipment rental and offers a small add-on still that can purify parts washer solvent continuously.
Disti-Kleen, Inc. Huntersville, NC 800/453-4784		5 sizes: 12 to 250 gallons, explosion proof, liners, scraped surface stills, vacuum.
Finish Thompson, Inc. Erie, PA 814/455-4478	Midway Industrial Supply Mounds View, MN 763/780-3000 800/279-1401	3 sizes: 5 to 55 gallons, CSA approved, explosion proof, liners, vacuum.
JB Systems Inc. LaGrange, GA 800/868-6204		Siva still, 5 sizes: 4 to 150 gallons, UL listed, explosion proof, liners, vacuum.
Kleentec Albert Lea, MN 800/435-5336		7.5 gallon, air cooled.
Lanair Janesville, WI 800/753-1601		Recyclit still, 8 gallons, air cooled, liners, portable.
NexGenEnviro Systems, Inc. Lindenhurst, NY 800/842-1630		9 sizes: 2 to 105 gallons, air cooled, explosion proof, liners. Water cooling and vacuum option on some. Integrated gun washer and still.
Omega Recycling Technologies Montreal, Quebec 800/361-1194	OSI Environmental Rogers, MN 800/628-7657	4 sizes: 3 to 30 gallons, UL listed, vacuum and condenser options (air, water, refrigerated) Integrated parts washer and stills, 2 integrated gun washers

		and stills. OSI offers rentals.
Onsite Waste Management Services Louisville, KY 800/255-6073		6 gallons, air cooled, explosion proof, integrated gun washer and solvent recovery unit.
PBR Industries Lindenhurst, NY 800/842-1630	American Fastener and Supply Circle Pines, MN 763/786-0146	Resolver-2 still, 9 sizes: 2 to 105 gallons, air cooled, explosion proof, liners, portable, scraped surface stills, vacuum.
Progressive Recovery, Inc. Dupo, IL 800/732-3793	Mike Kleinhans Menomonee Falls, WI 414/253-2299	15 to 495 gallons, can distill heat-sensitive materials, explosion proof, scraped surface stills, vacuum. Larger and special stills available.
Recycling Sciences, Inc. Prescott Valley, AZ 928/759-8814		8 models: 3 to 55 gallon, explosion proof, vacuum, water cooled.
Sawyer and Smith Corporation Castalia, OH 419/951-4818		Formeco still: 2 to 105 gallons, air or water cooled with optional vacuum. Larger and scraped stills available.
Sidewinder/Persyst Enterprises, Inc. Las Vegas, NV 702/362-9432		Sidewinder still, 5 gallon, UL listed, liners.
Solvent Kleene, Inc. Peabody, MA 978/531-2279		3 sizes: 8, 20 and 55 gallons, liners, portable, vacuum.
SRS Engineering Corp. Microdivision Murrieta, CA 951/677-6311		4 sizes: 3.5 to 55 gallons, CSA listed. Smaller units air cooled and use liners, larger units water cooled with vacuum as an option. Larger sizes include scraped surface and fractionation.
SystemOne Technologies, Inc. Miami, FL 800/711-1414	OSI Environmental Rogers, MN 800/628-7657	Integrated washers and stills to continuously recover solvent from parts and paint gun washers. OSI offers rentals.
Uni-Ram Corp. Tonawanda, NY 800/735-4331	KND Sales Osseo, MN 763/315-1057	6.5 and 20 gallon, 2 portable models that distill continuously from drums or parts washers. An integrated parts washer and still, an integrated gun washer and still.
Waste Recovery Designed Products, Inc. McDonald, PA 800/825-0094		Durastill, 5 sizes: 2 to 50 gallons, CSA and UL listed, liner, water cooled.

Appendix 2: Suppliers for high pressure wash systems

Table A2-1: Suppliers for high pressure wash systems. The table was issued by Washington State Department of Ecology [based on 11].

High-Pressure Wash Systems / Water Recycling systems			
Vendor	Location / City	Phone Number	Products / Description
Aaladin Industries	Elk Point, SD	(800) 411-4261	Hot/cold water pressure washers, steam cleaners.
AAR Boss	Aberdeen, NC	(800) 982-1988	Self-contained pressure spray / vacuum units for washdown and hazardous material recovery.
Acme Cleaning Equipment, Inc.	Houston, TX	(800) 231-9708	Hot and cold water pressure cleaning equipment, steam cleaners, water reclamation equipment.
Alcota Cleaning Systems, Inc.	Veradale, WA	(800) 255-6823	Surface cleaning and waste water treatment.
B&M Enterprises	Midlands	(800) 536-770	Steam cleaners, pressure washers, wastewater treatment systems, closed loop recycling systems.
The Hotsy Corporation	Englewood, CO	(800) 525-1976	Hot and cold water pressure washers, steam cleaners, wastewater recycling systems.
Landa Water Cleaning Systems	Camas, WA	(800) 792-6174	Hot and cold water pressure systems, steam cleaners, wash water recycling systems, wastewater treatment.
Niagara National Corporation	Atlanta, GA	(800) 635-8342	High pressure washers and wash water treatment and recycling systems.
RGF Environmental Systems	Palm Beach, FL	(800) 842-7771	Advanced water treatment / recycling systems.
Spartan Mfg Corp	Kernersville, NC	(336) 996-5585	Portable pressure washers & steam cleaning equipment, wastewater capture systems, all industries.

Appendix 3: Suppliers for adsorption process and solvent recovery

Possible suppliers for both technologies (adsorption process and solvent recovery system) are:

- Eisenmann Company [13]

EISENMANN AG

Tübinger Str.81
D-71032 Böbligen
Germany
P : +49 7031 78-0
F : +49 7031 78-1000

- MEGTEC company [14]

MEGTEC Systems SAS

Z.I. des Malines
32, rue des Malines
F-91090 Lisses
France
P : +33 1 69 89 47 93

- MTS company

MTS Environmental GmbH

Honeywellstrasse 18
D-63477 Maintal
Germany
P : +49 6181 94040

- Anguil company [15]

Anguil Europe

Spooner Industries Ltd.
Railway Road, Ilkley, West Yorkshire
LS29 8JB, England
Great Britain
Phone: + 44 (0) 1943 609505
Fax: + 44 (0) 1943 603190
<http://www.spooner.co.uk/>

Appendix 4: Chemical resistance selection chart for protective gloves

The ratings are abbreviated as follows: VG: Very Good; G: Good; F: Fair; P: Poor (not recommended). Chemicals marked with an asterisk (*) are for limited service.

Table A4-1: Chemical resistance selection chart [based on 31]

Chemical	Neoprene	Latex/Rubber	Butyl	Nitrile
Acetaldehyde*	VG	G	VG	G
Acetic acid	VG	VG	VG	VG
Acetone*	G	VG	VG	P
Ammonium hydroxide	VG	VG	VG	VG
Amy acetate*	F	P	F	P
Aniline	G	F	F	P
Benzaldehyde*	F	F	G	G
Benzene*	P	P	P	F
Butyl acetate	G	F	F	P
Butyl alcohol	VG	VG	VG	VG
Carbon disulphide	F	F	F	F
Carbon tetrachloride*	F	P	P	G
Castor oil	F	P	F	VG
Chlorobenzene*	F	P	F	P
Chloroform*	G	P	P	F
Chloronaphthalene	F	P	F	F
Chromic acid (50%)	F	P	F	F
Citric acid (10%)	VG	VG	VG	VG
Cyclohexanol	G	F	G	VG
Dibutyl phthalate*	G	P	G	G
Diesel fuel	G	P	P	VG
Diisobutyl ketone	P	F	G	P
Dimethylformamide	F	F	G	G
Diocetyl phthalate	G	P	F	VG
Dioxane	VG	G	G	G
Epoxy resins, dry	VG	VG	VG	VG
Ethyl acetate*	G	F	G	F
Ethyl alcohol	VG	VG	VG	VG
Ethyl ether*	VG	G	VG	G

Chemical	Neoprene	Latex/Rubber	Butyl	Nitrile
Ethylene dichloride*	F	P	F	P
Ethylene glycol	VG	VG	VG	VG
Formaldehyde	VG	VG	VG	VG
Formic acid	VG	VG	VG	VG
Freon 11	G	P	F	G
Freon 12	G	P	F	G
Freon 21	G	P	F	G
Freon 22	G	P	F	G
Furfural*	G	G	G	G
Gasoline, leaded	G	P	F	VG
Gasoline, unleaded	G	P	F	VG
Glycerin	VG	VG	VG	VG
Hexane	F	P	P	G
Hydrazine (65%)	F	G	G	G
Hydrochloric acid	VG	G	G	G
Hydrofluoric acid (48%)	VG	G	G	G
Hydrogen peroxide (30%)	G	G	G	G
Hydroquinone	G	G	G	F
Isooctane	F	P	P	VG
Kerosene	VG	F	F	VG
Ketones	G	VG	VG	P
Lacquer thinners	G	F	F	P
Lactic acid (85%)	VG	VG	VG	VG
Lauric acid (36%)	VG	F	VG	VG
Lineolic acid	VG	P	F	G
Linseed oil	VG	P	F	VG
Maleic acid	VG	VG	VG	VG
Methyl alcohol	VG	VG	VG	VG
Methylamine	F	F	G	G
Methyl bromide	G	F	G	F
Methyl chloride*	P	P	P	P
Methyl ethyl ketone*	G	G	VG	P
Methyl isobutyl ketone*	F	F	VG	P
Methyl methacrylate	G	G	VG	F
Monoethanolamine	VG	G	VG	VG
Morpholine	VG	VG	VG	G

Chemical	Neoprene	Latex/Rubber	Butyl	Nitrile
Naphtalene	G	F	F	G
Napthas, aliphatic	VG	F	F	VG
Napthas, aromatic	G	P	P	G
Nitric acid*	G	F	F	F
Nitric acid, red and white fuming	P	P	P	P
Nitromethane (95.5%)*	F	P	F	F
Nitropropane (95.5%)	F	P	F	F
Octyl alcohol	VG	VG	VG	VG
Oleic acid	VG	F	G	VG
Oxalic acid	VG	VG	VG	VG
Palmitic acid	VG	VG	VG	VG
Perchloric acid (60%)	VG	F	G	G
Perchloroethylene	F	P	P	G
Petroleum distillates (naphtha)	G	P	P	VG
Phenol	VG	F	G	F
Phosphoric acid	VG	G	VG	VG
Potassium hydroxide	VG	VG	VG	VG
Propyl acetate	G	F	G	F
Propyl alcohol	VG	VG	VG	VG
Propyl alcohol (iso)	VG	VG	VG	VG
Sodium hydroxide	VG	VG	VG	VG
Styrene	P	P	P	F
Styrene (100%)	P	P	P	F
Sulphuric acid	G	G	G	G
Tannic acid (65)	VG	VG	VG	VG
Tetrahydrofuran	P	F	F	F
Toluene*	F	P	P	F
Toluene diisocyanate (TDI)	F	G	G	F
Trichloroethylene*	F	F	P	G
Triethanolamine (85%)	VG	G	G	VG
Tung oil	VG	P	F	VG
Turpentine	G	F	F	VG
Xylene*	P	P	P	F

Appendix 5: Storage

Storage incompatibilities

Table A5-1: Storage of hazardous substances commonly used in the industry [70]

		Formic acid	Solution of ammonia	Solution of iron chloride (III)	Solution of iron chloride (III) sulfate	Acetic acid	Hydrofluoric acid	Solution of potassium hydroxide	Solution of sodium hydroxide	Solution of sodium hydrogensulfite	Solution of sodium hypochlorite	Peracetic acid	Phosphoric acid	Nitric acid	Hydrochloric acid	Sulphuric acid	Hydrogen peroxide
	Storage category	8	8	8	8	3	6.1	8	8	10/12	5	5	8	5	8	8	5
Formic acid	8	Yellow	Yellow	Green	Green	Green	Green	Yellow	Yellow	Red	Red	Yellow	Green	Red	Green	Red	Red
Solution of ammonia	8	Yellow	Grey	Yellow	Yellow	Yellow	Yellow	Red	Red	Yellow	Yellow	Red	Yellow	Red	Yellow	Yellow	Yellow
Solution of iron chloride (III)	8	Green	Yellow	Grey	Green	Green	Green	Yellow	Yellow	Red	Red	Yellow	Green	Green	Green	Green	Yellow
Solution of iron chloride (III) sulfate	8	Green	Yellow	Green	Grey	Green	Green	Yellow	Yellow	Red	Red	Yellow	Green	Green	Green	Green	Yellow
Acetic acid	3	Green	Yellow	Green	Green	Grey	Green	Yellow	Yellow	Red	Red	Yellow	Green	Red	Green	Green	Red
Hydrofluoric acid	6.1	Green	Yellow	Green	Green	Green	Grey	Yellow	Yellow	Red	Red	Red	Green	Green	Green	Red	Green
Solution of potassium hydroxide	8	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Grey	Green	Yellow	Green	Red	Yellow	Yellow	Yellow	Yellow	Yellow
Solution of sodium hydroxide	8	Yellow	Red	Yellow	Yellow	Yellow	Yellow	Green	Grey	Yellow	Green	Red	Yellow	Yellow	Yellow	Yellow	Yellow
Solution of sodium hydrogensulfite	10/12	Red	Yellow	Red	Red	Red	Red	Yellow	Yellow	Grey	Red	Red	Red	Red	Red	Red	Yellow
Solution of sodium hypochlorite	5	Red	Yellow	Red	Red	Red	Red	Green	Green	Red	Grey	Red	Red	Red	Red	Red	Yellow
Peracetic acid	5	Yellow	Red	Yellow	Yellow	Yellow	Red	Red	Red	Red	Red	Grey	Red	Red	Red	Red	Red
Phosphoric acid	8	Green	Yellow	Green	Green	Green	Green	Yellow	Yellow	Red	Red	Red	Grey	Green	Green	Green	Green
Nitric acid	5	Red	Red	Green	Green	Red	Green	Yellow	Yellow	Red	Red	Red	Green	Grey	Red	Red	Red
Hydrochloric acid	8	Green	Yellow	Green	Green	Green	Green	Yellow	Yellow	Red	Red	Red	Green	Red	Grey	Red	Green
Sulphuric acid	8	Red	Yellow	Green	Green	Green	Red	Yellow	Yellow	Red	Red	Red	Green	Red	Red	Grey	Green
Hydrogen peroxide	5	Red	Yellow	Yellow	Yellow	Red	Green	Yellow	Yellow	Yellow	Yellow	Red	Green	Red	Green	Green	Grey

Security distances

Table A5-2: Neighbourhood risk evaluation [based on 71]

Type of storage building	Neighbouring building activity		
	Low danger ²⁷	Medium danger ²⁸	High danger ²⁹
Specifically resistant to fire	Low	Low	Low
Non-flammable (concrete)	Low	Medium	High
Flammable (wood)	Medium	High	High

Table A5-3: Safety distance in meters between outside warehouses and buildings, structures and facilities [based on 71]

Neighbourhood risks (Table A5-2)	Storage in containers (in litres)					
	Categories F1 and F2			Categories F3, F4 and F5		
	Up to 5,000	Up to 50,000	Above 50,000	Up to 5,000	Up to 50,000	Above 50,000
Low	5	10	15	-	5	8
Medium	10	15	20	5	8	12
High	15	20	25	8	12	15

Table A5-4: Safety distance in m between unburied tanks and buildings, structures and facilities [based on 71]

Neighbourhood risks (Table A5-2)	Storage in tanks (in m ³)					
	Categories F1 and F2			Categories F3, F4 and F5		
	Tank resistant to overpressure	Vertical tank		Tank resistant to overpressure	Vertical tank	
		Up to 500	Above 500		Up to 500	Above 500
Low	12	20	30	6	10	15
Medium	16	25	35	8	12	18
High	20	30	40	10	15	20










²⁷ Production, treatment and storage of non-flammable materials

²⁸ Construction of devices, car repair, offices, apartments

²⁹ Storage and treatment of hazardous materials, woodworking, printery, professional accommodation, buildings with space for a large number of occupants

Appendix 6: Fire protection

Table A6-1: Main hazardous product classes concerned by fire or explosion hazards

Hazard class	GHS ³⁰ pictogram	Hazard statement codes
Explosive		H200 – Unstable explosive H201 – Explosive ; mass explosion hazard H202 – Explosive ; severe projection hazard H203 – Explosions ; fire, blast or projection hazard H204 – Fire or projection hazard
Flammable gases		H220 – Extremely flammable gas
Aerosols		H222 – Extremely flammable aerosol H223 – Flammable aerosol H229 – Pressurized container : may burst if heated
Oxidizing gases		H270 – May cause or intensify fire ; oxidizer
Gas under pressure		H280 – Contains gas under pressure ; may explode if heated
Flammable liquids		H224 – Extremely flammable liquid and vapour H225 – Highly flammable liquid and vapour H226 – Flammable liquid and vapour
Flammable solids		H228 – Flammable solid
Substances and mixtures which in contact with water emit flammable gases		H260 – In contact with water releases flammable gases which may ignite spontaneously H261 - In contact with water releases flammable gases
Oxidizing liquids or solids		H271 – May cause fire or explosion ; strong oxidizer H272 – May intensify fire, oxidizer

³⁰ Globally Harmonized System of Classification and Labelling of Chemicals (GHS)

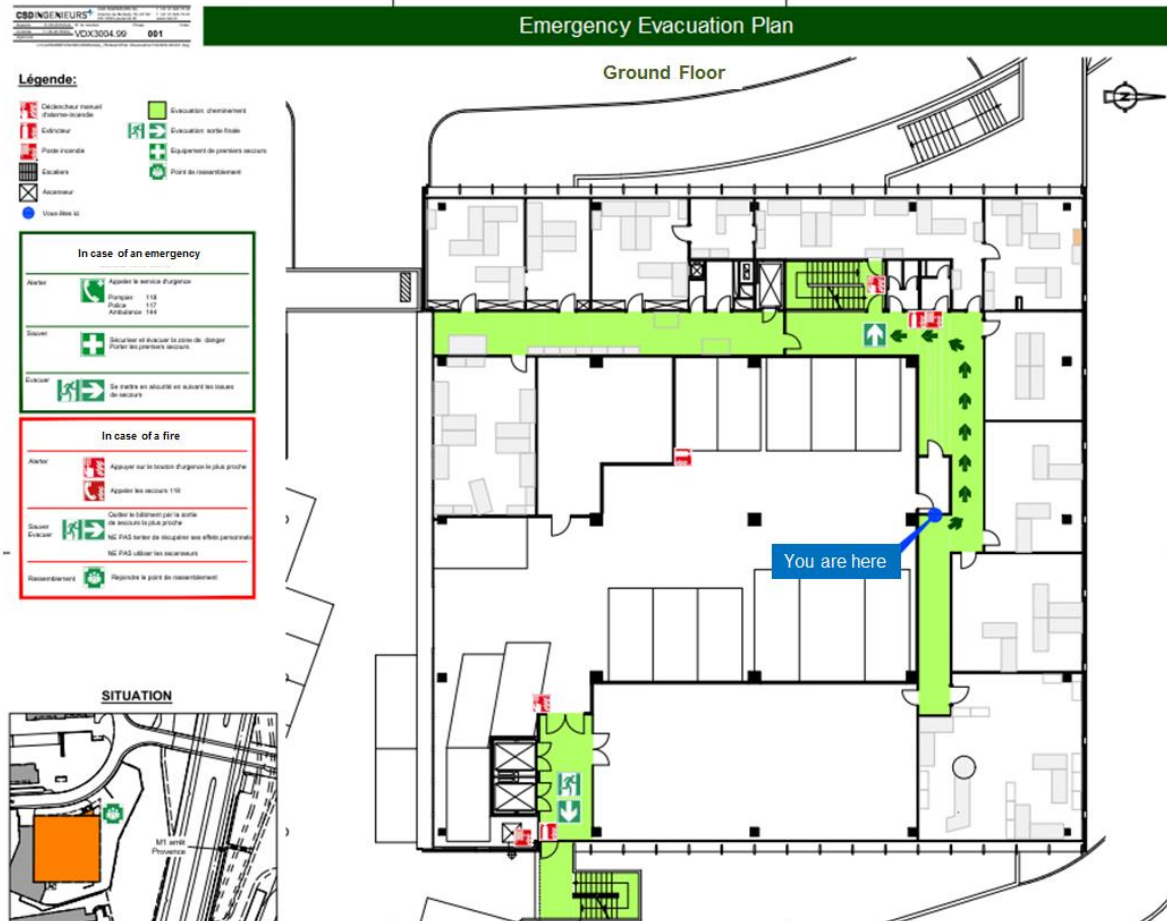


Figure A6-1: Emergency evacuation plan [72]