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CoE65 CABICHEM

Handbook

Chemical and Biological Waste Management

EU CBRN CoE - Project 65 is implemented by:

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1 Chemical Waste

1.1. Definitions and State-of-the-Art

Hazardous Chemical Waste: a "difficult" definition

In the following overview, it is possible to have an idea how the definition of waste (either chemical, biological or conventional urban waste) may pose problems and affect radically the decision for a proper destination of the waste stream. In fact, defining a material 'waste' or 'not-waste' is a critical choice, in order to minimize the global amount of compounds and material to be disposed of.

The Organisation for Economic Cooperation and Development (OECD) is an international organisation that works to build better policies for better lives. The OECD defines **waste** in general terms as: "*materials that are not prime products (that is, products produced for the market) for which the generator has no further use in terms of his/her own purposes of production, transformation or consumption, and of which he/she wants to dispose*."

The United Nations Environment Programme (UNEP) defines **waste** as:

"*objects which the owner does not want, need or use any longer, which require treatment and/or disposal*".

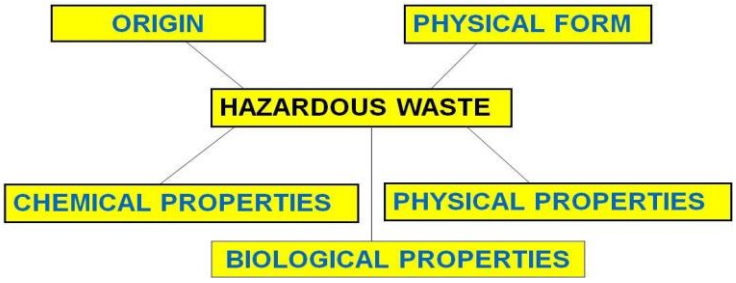
However, when waste materials and residuals from research, chemical, biological or hospital laboratories are concerned, it is necessary to define the concept of hazardous waste as: "*waste that, owing to their toxic, infectious, radioactive or flammable properties pose a substantial actual or potential hazard to the health of humans and other living organisms and the environment*".

Obviously, sources of hazardous waste include not only research and chemical laboratories, but also hospitals, timber treatment, petrol storage, metal finishing, paint manufacture, vehicle servicing, tanneries, agriculture/horticulture, electricity distribution and dry cleaning facilities.

Examples of hazardous waste substances commonly produced in a chemical or technical laboratory can be:

- Waste and opened surplus chemicals
- Expired or off-specification chemicals
- Medicines and prescription drugs
- Empty chemical drums and other chemical containers (if not properly rinsed or washed)
- Thermometers and other items containing mercury
- Non-returnable gas cylinders or pressurized chemicals
- Residue of spill clean-up materials-contaminated rags and absorbents
- Non-radioactive lead shielding and lead scrap
- Photographic film processing solutions
- Used motor oil, vacuum pump oil, lubricating oil
- Pesticides
- Used solvents
- Batteries
- Paint, paint thinners, brush cleaners, linseed oil
- Heavy metal containing waste or products (in particular, As, Ba, Cd, Cr, Pb, Hg, Se and Ag)

Currently, at worldwide level, there is no one unique, commonly-accepted definition of hazardous waste. When the Global Waste Survey - the first attempt to gain a worldwide picture of hazardous waste - was published in 1995, it found that there were 'almost as many definitions as countries'.
In fact, starting from different point of views and taking into consideration complementary aspects of the risk, the hazard associated with a waste may depends on several factors:



Each country has indeed its own interpretation and various terms are used to refer to the 'waste', such as 'chemical', 'special', 'poisonous' or 'toxic'.
The definitions today differ according to their differing objectives. In some countries, such as the USA and Germany, waste which cannot be disposed of with municipal solid waste are separately classified. In other countries, such as Denmark, the objective of the definition is to ensure the most appropriate treatment.

Other ways of defining hazardous waste might include one based on its recycling potential. This is the Italian approach to the classification of urban waste and it may even present some peculiarities on a municipal basis.
In low-income economies, there is often an inadequate identification of the waste stream which is the complete flow of waste from its domestic or industrial source through to recovery, recycling or final disposal.
This lack of clarity can lead to an increase in pollution of the environment as well as increased risks to human health.

Fig. 1.1 Open-air unprotected use of mercury for gold extraction and mining

An exemplar case is the massive use of liquid mercury in Brazilian Amazonas to extract gold from river sands and surface mines (Fig. 1.1). The total-loss approach in the use of that metal to obtain in-situ the Au-Hg amalgam is causing an ever-increasing concern for relevantly sever pollution by Hg of remote areas.

Nevertheless, although difficult, waste classification is an important early step in developing a **waste management system**.
A rapid overview on some examples of definitions for hazardous waste is hereafter given. The reader is, however, invited to refer directly to the original bibliographic references for each definition.
The *Basel Convention* defines 45 categories of waste materials (Annex 1) that are presumed to be hazardous and the substances or materials that fulfil these requirements must also exhibit one or more hazardous characteristics, such as: flammable, oxidising, poisonous, infectious, corrosive or environmentally toxic.
According to the *United Nations Transport of Dangerous Goods Code*, that provides the rules for the safe transport of any hazardous material (not only waste, but also intrinsically dangerous raw materials or compounds), all those waste materials (other than radioactive ones) which, by reason of their chemical activity or toxic, explosive, corrosive nature or other characteristics, cause danger or are likely to cause danger to health or the environment are hazardous waste.

In the United States of America, the waste is listed under *Environmental Protection Agency*, EPA, regulations. A solid waste is a hazardous waste if it is specifically listed as a known hazardous waste or meets the characteristics of a hazardous waste. Listed waste are waste materials from common manufacturing and industrial processes, specific industries and can be generated from discarded commercial products. Characteristic waste are waste materials that exhibit any one or more of the following characteristic properties: ignitability, corrosivity, reactivity or toxicity.
In addition, it is worth to highlight that the waste is declared hazardous by the generator. This is a relevant point of difference, with respect to other regulations, as it moves the responsibility in defining a waste hazardous or non-hazardous to the entity which produces the unwanted material.

The *European Waste Catalogue* follows, on the other hand, a strict hierarchically structured core list of 850 types of waste. Of these, around 420 are classified as hazardous waste and these are divided into 19 main categories.

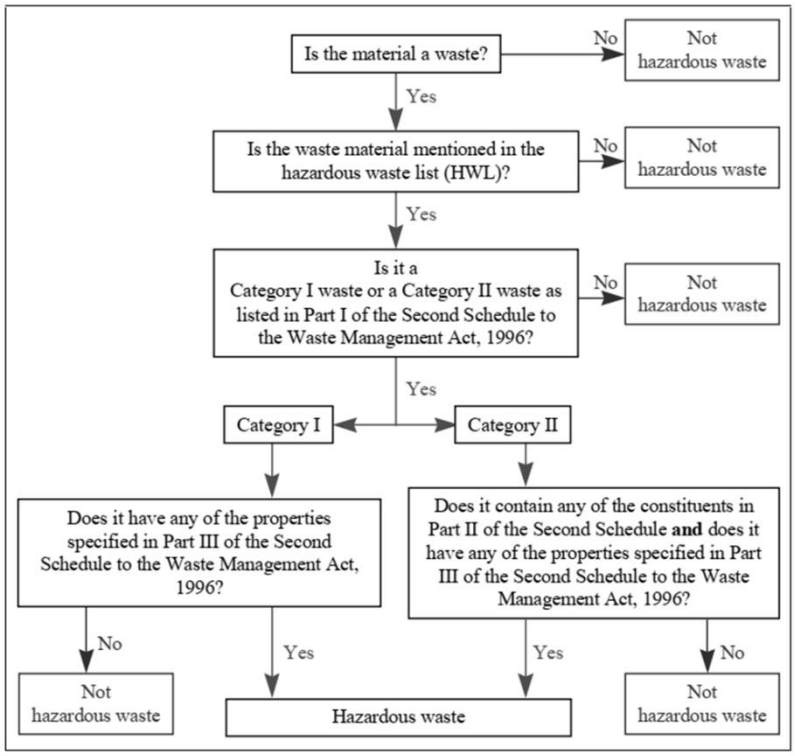


Fig. 1.2 Hazardous waste flowchart according to the European Waste Catalogue (Acts 1996 and 2001); available from EPA Publications

So, to summarize these brief remarks, two questions may arise.

Why is it necessary to define a waste? It is crucial in order to decide whether or not that waste should be controlled. This is piece of information is essential both for the generator and for the regulator.

Why is it useful to create a list? Lists are clear, simple, easily accessible and, in particular, they do not need specific investigation work for testing.
In fact, producing a list of waste materials, which are automatically considered hazardous, is a smart and straightforward approach and it has particular benefits in weak economies where facilities for testing and technical analysis are scarce or simply do not exist.

1.2 Methods of identification

Several approaches can be followed for the identification and classification of a waste.

- The use of lists. It is worth mentioning the most relevant ones, *i.e*. the Annex I to the Basel Convention, Basel List A, European Union European Waste Catalogue or the United States EPA list.
- By origin, taking into account the process or the manufacture generating the waste. This is the case with the Annex II to the Basel Convention.
- By hazardous characteristics, *e.g*. toxicity, reactivity. This is the approach found in the Annex III to Basel Convention.
- By chemical and physical properties. The state of the material or compound is crucial too, in order to address properly the waste in the correct waste stream, *e.g*., inorganic, organic, oily, sludge-like waste.

It is, additionally, necessary to match classification to objectives and to the final fate of the waste. When the main goal is to build disposal facilities, a classification based on treatability is the most appropriate. In order to ensure a safe transport of the hazardous material, then the UN Hazard Classification may be the most useful option. Or, in order to implement a waste minimisation programme, a system based on process origin and/or waste stream may be best choice. When an easy separation of hazardous waste from other waste is needed, a list is an appropriate rule-of-thumb to cope with this kind of problems.

However, **no method will suit all cases**.
In fact, all methods show some drawbacks. For instance, the origin as a means of identifying waste has limitations, as it is not possible to have a precise idea of its composition and hence the hazards it poses. This is true, in particular, in the case of miscellaneous or ubiquitous waste, such as contaminated soils, dusts,

redundant pesticides from agriculture or hospital healthcare waste. It is not easy, therefore, to identify a clear waste stream in which the unwanted material has to be addressed to.

As mentioned above, the classification by hazardous characteristics has been primarily defined by the UN Committee on the Transport of Dangerous Goods by Road or Rail, ADR, which fixed in lists the waste characteristics.

UN Class	Dangerous Goods	Division (s)	Classification
1	Explosives	1.1 - 1.6	Explosive
2	Gases	2.1	Flammable gas
		2.2	Non-flammable, non-toxic gas
		2.3	Toxic gas
3	Flammable liquid		Flammable liquid
4	Flammable solids	4.1	Flammable solid
		4.2	Spontaneously combustible substance
		4.3	Substance which in contact with water emits flammable gas
5	Oxidising substances	5.1	Oxidising substance
		5.2	Organic peroxide
6	Toxic substances	6.1	Toxic substance
		6.2	Infectious substance
7	Radioactive material		Radioactive material
8	Corrosive substances		Corrosive substance
9	Miscellaneous dangerous goods		Miscellaneous dangerous goods

Fig. 1.3 UN Hazard Identifiers of the UN Committee on the Transport of Dangerous Goods by Road or Rail (ADR)

Such nine parameters have been adopted by the Basel Convention in the Annex III and they were split into 13 main characteristics, based on ADR rules, that are represented as codes H1-H13.

It is worthwhile to define in deeper detail some common hazardous properties.

Toxicity. A toxic waste is harmful or fatal when ingested, inhaled or absorbed through the skin.
Some classical examples commonly found in chemical research laboratories are, *e.g.*, spent cyanide solutions, disposed pesticides or carbonyl compounds and their

complexes. Toxic waste disposed of on land may result in contaminated leachate. Leaching from landfills into groundwater and then into drinkable water is one of the most common ways of exposure for population.
The United States Environmental Protection Agency has devised a toxicity characteristic leaching procedure, TCLP, test to identify waste likely to leach hazardous concentrations of toxic constituents.
In the TCLP procedure, the pH of the sample material is first established and then leached with an acetic acid / sodium hydroxide solution at a 1:20 mix of sample to solvent. For example, a TCLP jug may contain 100 g of sample and 2000 mL of solution. The leachate mixture is sealed in extraction vessel for general analytes, or possibly pressure-sealed as in zero-headspace extractions, ZHE, for volatile organic compounds and tumbled for 18 h to simulate an extended leaching time in the ground. It is then filtered so that only the solution (not the sample) remains and this is then analysed.

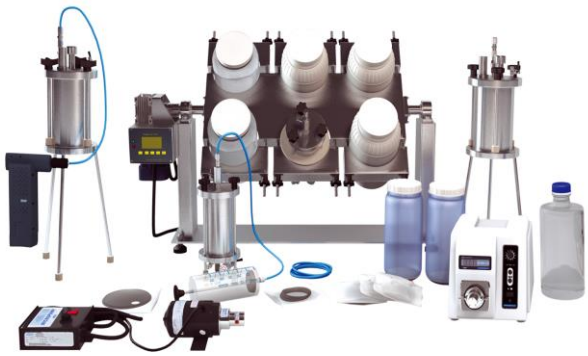


Fig. 1.4 US-EPA toxicity characteristic leaching procedure (TCLP). Volatile and Non-volatile Substance Leaching Equipment

The Environmental Compliance Supervisor (the gatekeeper) at a typical municipal landfill uses TCLP data to determine whether a waste may be accepted into the facility.
If TCLP analytical results are below the TCLP D-list maximum contamination levels (MCLs) the waste can be accepted. If they are above these levels the waste must be taken to a hazardous waste disposal facility and the cost of disposal may increase from about 20 USD/ton to as much as 500 USD/ton.

Corrosivity. Corrosive compounds are typically acids or alkalis that are capable of dissolving human flesh and corroding metal, such as storage tanks and drums. Among them, acids from metals cleaning processes, *e.g.*, ferric chloride from

printed circuit board manufacture; liquors from steel manufacture, highly alkaline solutions (NaOH, KOH) as well as concentrated H_2O_2, that, thanks to its strong oxidising capability, is able to etch metals and organic materials (with the additional potential problem due to the formation of unstable explosive organic peroxides).

Ignitability. Ignitable waste can generate fires under certain conditions or are spontaneously combustible. Classical examples are: waste oils (especially, in chemical laboratories, from oil baths or vacuum pumps), used solvents (in particular, the large amounts from liquid chromatography), organic cleaning materials as well as paint waste.

Reactivity. Reactive waste are unstable under normal conditions, *i.e*. the conditions of pressure, moisture and temperature under which they are conventionally employed. They can cause explosions and the emission of toxic fumes, gases or vapours. Peroxide solutions or hypochlorite solutions or solids belong to this class of hazardous waste.

Particular attention must be paid to unstable reactive waste substances, as they can pose severe problems at any stage of the waste management life cycle and handling. In particular, the mixing of these compounds with other categories of waste (*e.g*. strong oxidants with reducing chemicals) may generate undesired run-off reactions, leading to sudden explosions.

Environmental Toxicity. Eco-toxic waste materials are harmful or fatal to other species in the natural environment or to the ecological integrity of their habitats. Well-known examples are heavy metals, detergents, oils, fats or soluble salts. Even though their presence is not hazardous for human beings, low levels of these pollutants may interfere negatively with the metabolic and living processes of other animal species, such as fishes, crustaceans, insects, etc. For this reason, human toxicity standards are not always appropriate when considering and estimating environmental toxicity problems.

The classification based on chemical and physical properties splits the waste in four main groups.

- *Inorganic waste*, *e.g.*, acids, alkalis, heavy metals, cyanides, wastewaters from electroplating;
- *Organic waste*, *e.g*. pesticides, halogenated and non-halogenated solvents, PCBs;

- *Oily waste*, *e.g*. lubricating oils, hydraulic fluids, contaminated fuel oils;
- *Sludges*, *e.g*. from metal working, painting, wastewater treatment.

This kind of classification is typically found in most research laboratories for the immediate handling and separation of residuals and waste materials. Conversely, on a macroscale level, the relative composition of hazardous waste types by region of the world, according to the different industrial manufacture that are present in the area.

Some kinds of waste may be excluded from the legal definition of hazardous waste and thus do not necessarily follow the conventional waste stream as the other hazardous materials. These are various, but may include:

Hazardous waste from households. This kind of residuals are outside the controls in many countries.

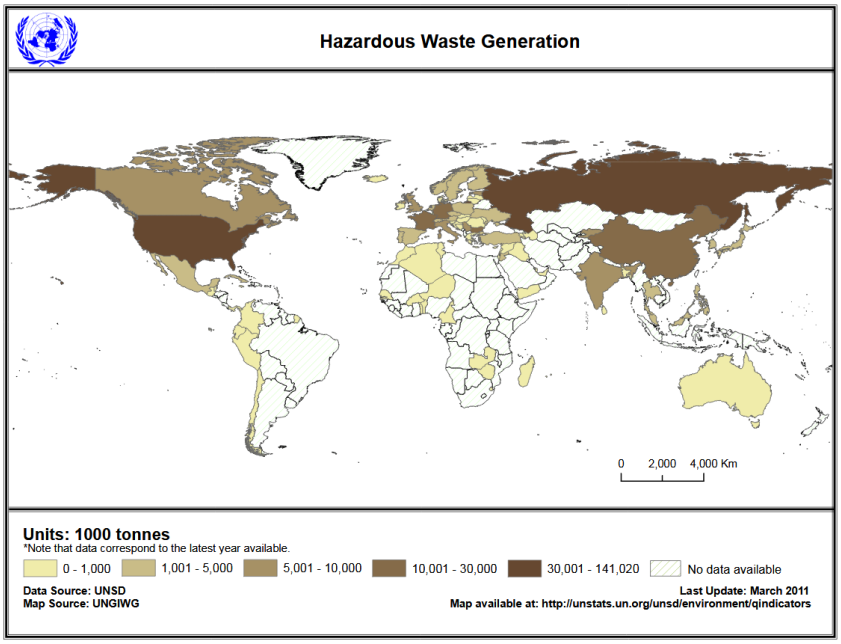
Small quantity generators. They are often placed outside the system, at least initially. Aqueous effluents discharged to sewer or treated on-site. Because of the large content of water they are controlled separately from hazardous waste in most countries.

Sewage sludge. They are excluded in some countries.

Mining waste. They are often excluded.

Agricultural waste. They are often excluded

Nuclear waste. They are always excluded, as they have to comply more stringent regulations at international level.



Since 1990s, a growing attention has been also paid to the ecological footprint of the compounds we use. Classical examples for this are persistent chemicals, such as dichlorodiphenyltrichloroethane, DDT, and polychlorinated organic compounds or chlorofluorocarbides, CFC, as they show abnormal persistence, very poor degradability and a marked bioaccumulation potential. In other case, the mobility in soil or other adverse effects have to be taken into careful account. This information is typically found in the Safety Data Sheet for the compound the waste is originated from.

1.3 Waste or not waste?

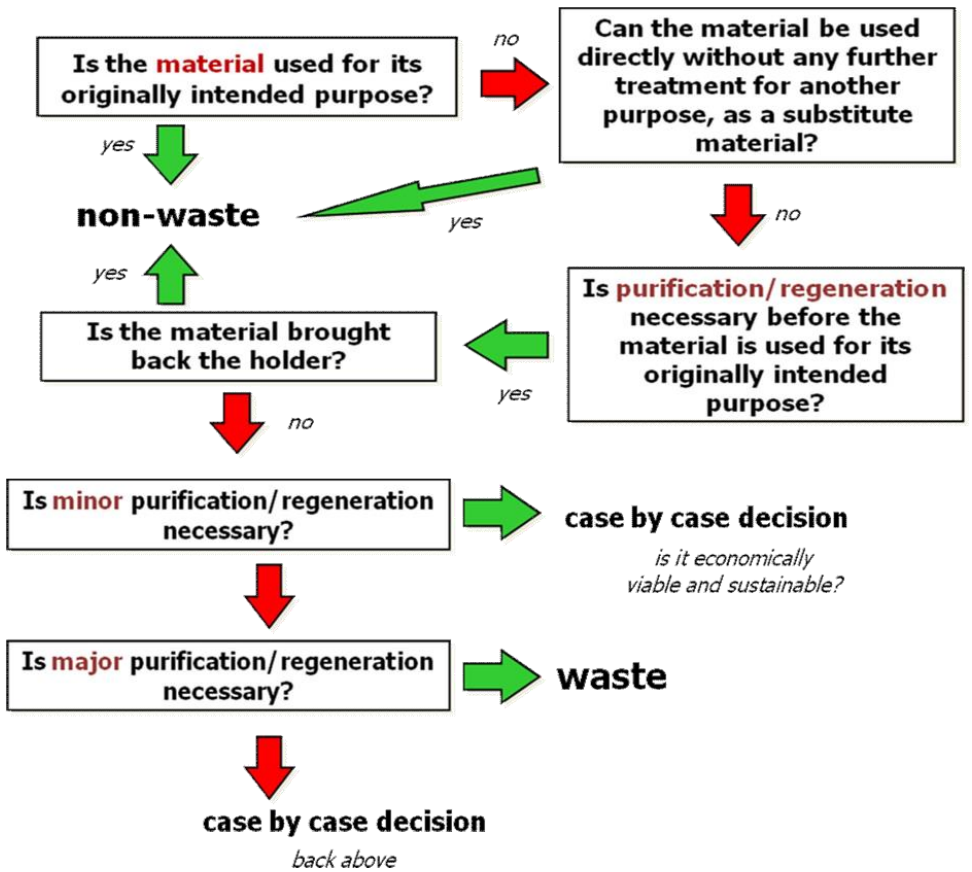
Important and very useful guidelines for distinguishing a waste from a non-waste are given by the Organisation for Economic Co-operation and Development, OECD. They are structured as a series of questions and criteria that may help the user to evaluate properly whether a material/substance/chemical compound is to be considered a **waste** or a **secondary raw material**.

- Is the material produced intentionally?
- Is the material made in response to market demand?
- Is the production of the material subject to quality control?
- Does the material meet well developed nationally and internationally recognised specifications/standards?
- Do these standards include environmental considerations, in addition to technical or economic considerations?
- Is the material still suitable for its originally intended purpose?
- Can the material be used for another purpose as a substitute material?
- Is this processing limited to minor repair?
- Will the material actually be used in a production process?
- Does the material have an identified use?
- Can the material be used in its present form or in the same way as a raw material without being subjected to a recovery operation?
- Can the material be used only after it has been subjected to a recovery operation?
- Is the use of the material as environmentally sound as that of a primary product?
- Does the use of the material in a production process cause any increased risks to human health or the environment greater than the use of the corresponding raw material?
- Is the overall economic value of the material negative?
- Is the material no longer part of the normal commercial cycle or chain of utility?

- Is further processing required before the material can be directly used in a manufacturing/commercial application?

1.4 End of life materials

All the considerations above, that are valid for any material at the end of its life cycle, can be summarized and sketched in a flowchart of practical use.



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2. Biological Waste

2.1 Definitions and State-of-the-Art

Biohazardous waste

Biohazardous waste are public and private Health-care waste products which may carry human pathogens or biohazards. Biohazards are infectious agents or hazardous biological materials that present a risk or potential risk to the health of humans, animals or the environment. The risk can be direct through infection or indirect through damage to the environment. The most prominent feature of biohazardous waste is its thus its potential infectiousness and, consequently, the term biohazardous waste is often replaced by the term infectious waste. The interpretation of the definition may slightly vary according to national circumstances, policies and regulations.

Biohazardous materials include certain types of recombinant DNA, organisms and viruses infectious to humans, animals or plants (e.g. parasites, viruses, bacteria, fungi, prions, rickettsia), biologically active agents (i.e. toxins, allergens, venoms) that may cause disease in other living organism or cause significant impact to the environment or community. Since Biohazardous waste originates from Health-care facilities and/or research laboratories, it is to be considered as a subcategory of health-care waste. Therefore manuals and scientific papers often refer to "health-care waste" as a comprehensive expression for those descriptions that apply to biohazardous waste too.

Most of the following classes are comprised of instruments and tools which are commonly used in health care facilities. Since they might have been in contact with infected patients or dangerous pathogens, they might fall within the category of biohazardous waste because of their potential infectiousness.

- *Sharps:* are all objects and materials that pose a potential risk of injury, invasion of the skin barrier in the human body or infection, due to their puncture or cut property. The main diseases of concern are infections which may be transmitted by subcutaneous introduction of the agent - for example, viral blood infections. The items that are able to cause cuts or puncture wounds, include all types of needles, scalpel and other blades, knives, infusion sets, ampoules, saws, broken glass, lancets, vials without content and nails. Whether or not they are infected, such items are usually considered as highly hazardous health-care waste. Sharps typically represent an example of potentially infectious health-care waste. Even if they represent about 1% of the total healthcare waste, they are a major source of disease transmission if not properly managed.

- *Pathological waste:* consists of all human tissues, organs, body parts (including, waste biopsy materials, tissues and anatomical parts from surgery, procedures, or autopsy), human fetuses and animal carcasses, blood and body fluids. Within this category, recognizable human or animal body parts are also called anatomical waste. This category should be considered as a subcategory of infectious waste, even though it may also include healthy body parts.
- *Human blood and blood products:* All human blood, blood products (such as serum, plasma, and other blood components) in liquid or semi-liquid form. Items contaminated with blood that, if com- pressed, would release blood in a liquid or semi-liquid form, or items caked with dried blood capable of being released during handling. Other body fluids or tissues containing visible blood. There is particular concern about infection with human immunodeficiency virus (HIV) and hepatitis viruses B and C, for which there is strong evidence of transmission via health-care waste. These viruses are generally transmitted through injuries from syringe needles contaminated by human blood.
- *Human Body Fluids:* Human body fluids in a liquid or semi-liquid state, including semen, vaginal secretions, cerebral spinal fluid, synovial fluid, pleural fluid, pericardial fluid, peritoneal fluid, amniotic fluid, and saliva from dental procedures. Also includes any other human body fluids visibly contaminated with blood, and all body fluids in situations where it is difficult or impossible to differentiate between body fluids.
- *Cultures and stock:* Discarded cultures and stocks of infectious agents or microorganism generated in the diagnosis, treatment, or immunization of a human being or animal or in any research relating to that diagnosis, treatment or immunization or in the production or testing of biologicals.
- *Materials contaminated with blood and body fluids:* Discarded materials or equipment contaminated with blood and its derivatives, other body fluids or excreta from patients potentially infected with hazardous communicable diseases, like dialysis equipment such as tubing and filters, disposable sheets, linen, aprons, gloves or laboratory coats contaminated with blood.

Biohazardous Waste Management

Biohazardous waste management is the segregation, collection, transport, treatment and disposal, managing and monitoring of biohazardous waste materials. The basic elements of minimal programmes of biohazardous waste management are represented by the following basic actions:

- assessment (quantitative and qualitative) of waste production;
- evaluation of local treatment and disposal options;

- segregation of biohazardous waste from general (or municipal) waste; establishment of internal rules for waste handling (storage, colour-coding, collection frequency, etc.);
- assignment of responsibilities within the health-care establishment;
- choice of suitable-or better-treatment and disposal options.

Biosafety Level

The designation of 4 levels of biosafety originated in the mid-1970s. There are four basic biosafety levels as determined by Centre for Disease Control and Prevention, CDC, and National Institute of Health, NIH, US Department of State, which describe the microbiological techniques, lab practices, safety equipment, lab facilities and waste management procedures necessary to protect workers and the environment. The levels are designated in ascending order, by degree of protection provided to personnel, the environment, and the community. Standard microbiological practices are common to all laboratories. Special microbiological practices enhance worker safety, environmental protection, and address the risk of handling agents requiring increasing levels of containment.

- **Biosafety Level 1:** is suitable for work involving well-characterized agents not known to consistently cause disease in immunocompetent adults human, and present minimal potential hazard to laboratory personnel and the environment. BSL-1 laboratories are not necessarily separated from the general traffic patterns in the building. Work is typically conducted on open bench tops using standards microbiological practices. Special containment equipment or facility design is not required, but may be used as determined by appropriate risk assessment. Laboratory personnel must have specific training in the procedures conducted in the laboratory and must be supervised by a scientist with training in microbiology or a related science.
- **Biosafety Level 2:** builds upon BSL-1. BSL-2 is suitable for work involving agents that pose moderate hazards to personnel and the environment. It differs from BSL-1 in that: 1) laboratory personnel have specific training in handling pathogenic agents and are supervised by scientists competent in handling infectious agents and associated procedures; 2) access to the laboratory is restricted when work is being conducted; and 3) all procedures in which infectious aerosols or splashes may be created are conducted in BSCs or other physical containment equipment.
- **Biosafety Level 3:** is applicable to clinical, diagnostic, teaching, research, or production facilities where work is performed with indigenous or exotic agents that may cause serious or potentially lethal disease through the inhalation route of exposure. Laboratory personnel must receive specific training in handling pathogenic and potentially lethal agents, and must be

supervised by scientists competent in handling infectious agents and associated procedures.

- **Biosafety Level 4:** is required for work with dangerous and exotic agents that pose a high individual risk of aerosol-transmitted laboratory infections and life-threatening disease that is frequently fatal, for which there are no vaccines or treatments, or a related agent with unknown risk of transmission. Agents with a close or identical antigenic relationship to agents requiring BSL-4 containment must be handled at this level until sufficient data are obtained either to confirm continued work at this level, or re-designate the level. Laboratory staff must have specific and thorough training in handling extremely hazardous infectious agents. Laboratory staff must understand the primary and secondary containment functions of standard and special practices, containment equipment, and laboratory design characteristics. All laboratory staff and supervisors must be competent in handling agents and procedures requiring BSL-4 containment. The laboratory supervisor in accordance with institutional policies controls access to the laboratory.

Health-care Waste

Health-care waste includes all the waste generated by health-care establishments, research facilities, and laboratories. In addition, it includes the waste originating from “minor” or “scattered” sources – such as that produced in the course of Health-care undertaken at home (dialysis, insulin injections, etc.)[5]. The concept embraces activities of diagnosis as well as preventive, curative and palliative treatments in the field of human medicine. In other words, all the waste produced by a medical institution (public or private), a medical research facility (public or private) or a laboratory (public or private), is to be considered as health-care waste.

As the awareness of the global increase of health care hazardous waste grew, WHO has produced a classification of such waste in order to facilitate the development of national and local management plans:

- Infectious waste;
- Pathological waste;
- Sharps;
- Pharmaceutical waste (Pharmaceutical waste includes expired, unused, spilt, and contaminated pharmaceutical products, drugs, vaccines, and sera that are no longer required and need to be disposed of appropriately. The category also includes discarded items used in the handling of pharmaceuticals, such as bottles or boxes with residues, gloves, masks, connecting tubing, and drug vials)
  - Genotoxic waste
  - Chemical waste

- Waste with high content of heavy metal
- Pressurized containers (many types of gas are used in health care and are often stored in pressurized cylinders, cartridges, and aerosol cans. Many of these, once empty or of no further use, although they may still contain residues, are reusable, but certain types notably aerosol cans must be disposed of. Whether inert or potentially harmful, gases in pressurized containers should always be handled with care; containers may explode if incinerated or accidentally punctured);
- Radioactive waste (radioactive waste includes solid, liquid, and gaseous materials contaminated with radionuclides. It is produced as a result of procedures such as in-vitro analysis of body tissue and fluid, in-vivo organ imaging and tumour localization, and various investigative and therapeutic practices).

2.2 Biological Overview

When employing biological agents, oftentimes protecting workers only is not enough. Systems must also be in place to protect the environment and the facility from possible contamination. Depending on the type of infectious biological microorganism, specific containment and safety procedures must be followed. Since there are different safety and security measures as the dangers associated with biological agents increase, laboratories are characterized by different biosafety levels and produce biohazardous waste with a different degree of risk. After identifying and explaining all the waste management procedures connected to the “type” of waste (sharps, liquids, etc.), a special attention will be devoted to how the procedures of waste management of the same “type” of waste change at the different “biorisk” levels. The degree of risk depends on the biological agents that potentially contaminated the waste and can basically be associated to the Bio-Safety Level of the facility.

Currently, in many countries, landfill has been and continues to be the predominant method for direct disposal of waste, most frequently without pre-treatment. This practice causes considerable concern. Of the total amount of waste generated by health-care activities, between 75% and 90% is non-risk or “general” health-care waste, comparable to domestic waste. It comes mostly from the administrative and housekeeping functions of healthcare establishments and may also include waste generated during maintenance of healthcare premises. The remaining 10-25% is regarded as hazardous healthcare waste material that may be infectious, toxic, chemical or radioactive. Moreover, the hazardous material may create a variety of health risks because it contains potentially harmful micro-organisms which can infect patients, workers and the general public. Other potential infectious risks may include the spread of drug-

resistant micro-organisms or new etiological agents of unknown zoonoses from health-care establishments into the environment. Infectious waste represents the majority of hazardous waste, up to 15% of the total waste from health-care activities.

Sharps typically represent an example of potentially infectious healthcare waste. Even if they represent about 1% of it, they are a major source of disease transmission if not properly managed. In effect, throughout the world, an estimated 16 billion injections are administered every year. Not all needles and syringes are properly disposed of, creating a risk of injury and infection and opportunities for re-use. WHO estimates that, in 2000, injections with contaminated syringes caused 21 million hepatitis B virus (HBV) infections (32% of all new infections), two million hepatitis C virus infections (40% of all new infections) and 260'000 HIV infections (5% of all new infections) worldwide. Many of these infections were avoidable if the syringes had been disposed of safely. The re-use of disposable syringes and needles for injections is particularly common in certain African, Asian and Central and Eastern European countries.
The major sources of biohazardous waste are: hospitals and other health-care establishments, laboratories and research centres, animal research and testing laboratories, mortuary and autopsy centres, nursing homes for the elderly and blood banks and collection services.
For example, high-income countries' hospitals, generate on average up to 0.5 kg of hazardous waste per bed per day; while low-income countries generate on average 0.2 kg of hazardous waste per hospital bed per day. However, classifications matter: health-care waste is often not separated into hazardous or non-hazardous waste in low-income countries making the real quantity of hazardous waste much higher.

Biohazardous waste management: what can we do?
Formulation of objectives and planning for their achievement are important tasks for improving healthcare waste management. The formulation of objectives shall be carried out basing on a national, regional and local need assessment. Planning requires the definition of a strategy that will facilitate careful implementation of the necessary measures and the appropriate allocation of resources according to the identified priorities. This is important for the motivation of authorities, healthcare workers, and the public and for defining further actions that may be needed.
Surveys on the generation of waste could be the basis for identifying opportunities - and setting targets - for waste minimization, reuse and recycling and cost reduction.

In both the short term and the long term, the actions involved in implementing effective healthcare waste management programmes require trans-disciplinary cooperation and interaction at all levels. Policies should be generated and coordinated globally, whereas the management practices implemented locally. Establishment of a national policy and a legal framework, training of personnel and raising public awareness are essential elements of successful healthcare waste management. Improved public awareness of the problem is vital in encouraging community participation in generating and implementing policies and programmes.
A holistic approach to health-care waste management should include a clear delineation of responsibilities, occupational health and safety programs, waste minimization and segregation, the development and adoption of safe and environmentally-sound technologies, and capacity building.

2.3 Biological Waste: International Guidelines

Many supranational organizations such as UNEP, WHO and so on, have recently opted for the use of guidelines to deal with sensitive matters such as human rights, the protection of the environment and bioethical issues. Hereafter, different approaches are shown:

WHO
The first approach is represented by WHO production of guidelines. As in many other supranational organizations, the Assembly represents the supreme decision making body of WHO, but it cannot adopt legally binding resolutions or decisions. The Assembly is assisted by the Executive Board whose main aims are to give effect to the policies of the Health Assembly, to advise it and to facilitate its work.
This structure, allows WHO to set guidelines and standards in specific matters related to healthcare. Considering the aim of this Handbook, the first example to be taken into account is a global and comprehensive guidance document, Safe management of waste from health-care activities, which addresses aspects such as regulatory framework, planning issues, waste minimization and recycling, handling, storage and transportation, treatment and disposal options, and training. WHO guidelines, which represent the international milestone in the health care waste management activities, are followed by a large number of more specific and detailed guidance documents which include:

- a monitoring tool
- a cost assessment tool
- a rapid assessment tool
- a policy paper

- guidance to develop national plans
- management of waste from injection activities
- management of waste at primary healthcare centres

UNEP

The second approach is related to the implementation of UNEP-Basel Convention. The Basel Convention is a legally binding instrument, but it is interesting to note that, along with the Convention, UNEP covers the same subjects with useful technical guidelines that might help the Parties to better implement the Convention at national level. This kind of instruments, if adopted, strengthen the Convention's provisions. The Technical guidelines on the environmentally sound management of biomedical and health care waste, for example, addresses aspects such as hazards of biomedical and healthcare waste, waste identification and classification, applicable state-of-the-art management, treatment and disposal technologies, the capacity building and so on.

Another example is depicted by the Guidance paper on hazardous characteristic Infectious substances, which contains guidelines related to infectiousness and "intrinsic" properties of Basel Convention hazard characteristics, definition of infectious organisms, degree of pathogenicity and route of exposure and infection, relationship with transport regulations, waste to which hazard characteristic might apply, and so on.

A comparison between the Basel Convention provisions and the specificity of the topics of these two guidelines clearly confirms what we have argued in the introduction of this paragraph on non-legally binding measures.

OECD

What we have seen in the case of UNEP - an international institution that coordinates the environmental activities of a universal institution, the United Nations - can also be seen in the case of other international organizations not strictly linked with the United Nations. A clear example related with the aim of our manual is represented by the case of the Environmentally Sound Management, ESM, of waste, promoted by OECD.

As we can see above, a legally binding instrument, paved the way for the adoption of non-legally binding instruments such as Resolutions and also guidelines. To better understand the significance of the guidelines, few lines of the Background of the "Guidance Manual on Environmentally Sound management of Waste" are here reproduced:

"Environmentally Sound Management (ESM) of Waste" had previously been referred to in most OECD Council Acts related to transboundary movements of wastes and in other international, regional and/or national regulations, where it is one of the underlying principles of waste management policies. In these earlier OECD Acts, "environmentally sound management of waste" was considered to

be a basic condition for allowing or prohibiting an export/import of waste within, as well as outside, the OECD area. However, it was also recognised that the scope and level of ESM vary greatly from one Member country to another. Lack of a clear definition and common understanding of ESM has led to challenges for the practical implementation of ESM instruments.[...] For these reasons, Member countries decided in 1999 to begin working towards international ESM "guidelines" for waste recovery facilities".

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3 Chemical Waste Management

3.1 Laboratory chemical waste best practices

In general, good prevention means a minimization of the potential risk. In the particular case of waste management, a **good waste handling** leads to a **minimization of emergency situations**.

It is essential to be aware of the guidelines and regulations at all level:

- Global rules and conventions
- National rules and laws
- Local rules and guide-lines
- Best practices at laboratory level

At laboratory scale, in most cases, no written rules are present for every operation in everyday work. Only a proper education and formation of the personnel and of the professionals is able to provide the worker with the most adequate know-how and the best practices to operate in a safe and environmentally respectful way.
However, the development of a **Laboratory Management Plan**, in which entities specify best waste management practices, could provide a very useful, operative, basis for workers and people in charge of waste disposal.

A long series of common mistakes can be found in research laboratories around the world. For instance:
- Waste not labelled with “waste (name of chemical)” and with the date of opening or production.
- Waste stored in open containers
- Waste stored without a secondary containment device

In many cases, the chemicals that can be found on the workplace are not more dangerous than those that are typically used at home, for household purposes.
Products, such as bleach, hydrochloric acid or hydrogen peroxide, are often used in everyday life and can easily be obtained from common commercial sources.
But on the workplace, the exposure may be greater, concentrations higher, exposure time longer: potential risk could be greater on the everyday workplace.

Laboratory Chemical Waste Practice covers several aspects:

- Accumulation of waste chemicals;
- Container Labelling and Marking
- Container Management
- Storage of Waste
- Acutely Hazardous Chemicals
- Unused, Unopened or Unknown Chemicals
- Obsolete Chemicals or Substances
- Chemical Inventory
- Sink Disposal of Chemical Substances

As an example, within the Italian National Research Council, the public institution for pure and applied research in Italy, each institute with laboratory activity (there are ca. 100 institutes across Italy on various scientific disciplines) possesses its own internal handbooks and guides with rules, guide-lines and best practices for laboratory work.

Fig. 3.1 Italian National Research Council, CNR
Internal handbook for best practices in chemical laboratory

3.2 Management of waste containers

Waste minimization can play a vital role in reducing the amount of hazardous waste generated annually. Waste generators are encouraged to investigate waste minimization techniques and incorporate these techniques as an integral part of the laboratory process and working practice.
Waste should be minimised and large amounts should not accumulate in the laboratory. In fact, a regular disposal from the laboratory containers must be part of the laboratory management plan. In addition, in order to fulfil a waste segregation policy, a separate residue container should be available, whenever a large amount of any particular type of waste is generated.

Waste chemicals collected either during the operation of a process or otherwise accumulated in the laboratory must be placed into **containers** that are in **good condition**, **compatible** with the contents, and able to contain the contents **without leaking**.
Containers used to collect waste chemicals must be clearly **marked** with the words '*Waste (name of chemical)*'. They must also be marked or **labelled** at the **time** waste is first placed in the container. Containers must have an open date listed on the container label, and when full or no longer being filled, a fill date. The open date is the earliest date that waste is placed in the container, whereas the fill date is the date that the container is filled and will no longer be used to accumulate waste.

Dozens of template of labels for chemical waste can be found in open resources in the Internet. Nevertheless, they must be **simple or nobody will fill them in**. It is very important that indications both in local language and in English, especially in those laboratories where a relevant fraction of foreign students/fellows/workers is present. It is also necessary in the countries where there is not only one national idiom.

Chemical Waste
Reference to MSDS
_____
***Full** chemical name*
Concentration (ca.%)
of main constituents

Does the waste contain any hazardous compound?
YES ☐ NO ☑
Section: _____
User: _____
Waste from ____ until _____
Phone: _____

Fig. 3.1 Examples of labels on laboratory containers needing major improvements

The label can be essential, but the **entire information** must be **filled in**. **Unused**, **unwanted** or **unopened chemicals** that are to be discarded must be labelled with the words '*Waste (name of chemical)*' and the date that they were determined to be unwanted or unusable.

Small or odd shaped containers, that are difficult to place a label on, must be placed in a larger sealed container and labelled on the outside (zip-lock bags, plastic containers, etc.).
Containers holding chemicals that cannot be identified by chemical name, chemical constituents, or process generating the waste must be labelled as '*Unknown Waste*' with the date that they are considered to be no longer needed.

Particular attention has to be paid to the choice of **waste containers** and their management, since they are often the main sources of mistakes and potential risk situations.

- Waste containers must be compatible with their contents.
- Waste containers must be kept closed except when adding or removing waste materials.
- Waste containers should be kept clean with no visible contamination on the outside of the container.
- Waste labels and markings must be readable and not defaced.
- Waste containers must not occupy useful positions and spaces under fumehoods.

Waste solids or liquids collected as part of a continuous process, such as effluents from HPLC chromatography, must be collected via tubes or pipes that are fed through a cap or other container closure to insure that the container is kept closed. This closure must be a positive closing lid. Parafilm™ (made of heavy paraffinic hydrocarbons, hence easily soluble in some organic solvents) or similar incomplete closures are not be acceptable, as vapours may escape easily.

Fig. 3.2 Example of correct storage of mobile phase outflow from HPLC

Liquid chemical waste
Containers used to collect waste chemicals on a frequent, routine basis must be **closed when a procedure or experiment has been completed**. For instance, containers used to collect acetone washes must be kept closed except when actively adding or removing waste from the container. This is a very common inaccuracy in most research laboratories.


Poor management of paint waste

The areas and the containers where waste chemicals are collected and accumulated must have **secondary containment** sufficient to collect any incidental spills from container failure. Waste containers should not be overfilled. Full containers must have at least a 10% **headspace** (or even 20% in hot climates) to allow for expansion and to avoid sudden expansion of the vapours inside the bottle/container.

Filled waste containers must be stored in a **secure area** under the control of the operator. In addition, primary waste containers must be stored for pick up in the room in which they were generated and not deposited in temporary inadequate areas. Filled containers of chemical waste must be removed from the laboratory within a **short period of time** (*ca*. 30-60 days) of the accumulation start date or the date a chemical becomes a waste.

Satellite Accumulation Sites are areas within an institution (university campus, institute, hospital, etc.) that generate small quantities of Hazardous Waste Materials.

For example, according to the Italian standards at the National Research Council, a satellite accumulation is an area that within 9 months accumulates:

- No more than **200 litres** of any hazardous waste.
- No more than **1 kg** of any highly hazardous waste.

Fumehoods are safety devices for the protection of laboratory personnel and not as storage areas. Storing and accumulating chemical waste effluents under a fumehood defeats the purpose of having such a prevention device. Hazardous waste containers are for waste and not for trash.

When waste containers are ready for pick-up, the bottles must be sorted by compatibility, in approved containers, with tighten caps and the contents must be properly identified.

Fig. 3.3 Containers ready for pick-up, properly labelled and located in secondary confinement vessel

Solid chemical waste

In the case of management of hazardous or contaminated solids, contaminated glass including broken glass, that cannot be cleaned easily (without the risk of harm for the operator), contaminated plastic parts, including tips, spent solid samples (*e.g.*, catalysts after use), contaminated absorbing paper, bench covers, silica gel sorbents (*e.g.*, for liquid chromatography), etc. must be disposed of in a separate special container.

Fig. 3.4 Containers for the collection of solid hazardous chemical waste

Highly Hazardous Waste

Commercial chemical products that are considered 'highly' hazardous when discarded (*e.g.*, labelled as 'P-List' waste by the United States Environmental Protection Agency) are subject to additional regulatory requirements. According to GHS, reactants and materials belonging to categories 1 (and 2) are to be considered highly hazardous chemicals.

Highly Hazardous Chemicals must be segregated into **separate containers**, clearly marked with the words '*Waste (name of chemical)*', and labelled with the date waste is first placed into that container. An inventory of the amount (in weight) of highly hazardous waste accumulated in the laboratory must be maintained by laboratory personnel: **a Waste Log**.

Laboratories may not accumulate more than **1 kg** of **Highly Hazardous Waste Materials** at any time. In addition, it is worth noting that **empty containers** of such chemicals must also be submitted for pick-up.

Special attention has to be paid to **unused** or **obsolete chemicals**. This kind of substances are frequently found in research laboratories where hundreds of reactants are often used for a short period of time and then are completely neglected, even for years.

An obsolete chemical is a reactant (compound) that will no longer be used for its intended purpose or will not be used again and needs to be discarded. **Routine inventory reviews** should be conducted to identify any obsolete chemical or substances at least once **every 6 months**. Main researchers or designated personnel should develop and maintain such inventory. Any obsolete chemical or substance should be removed from storage, placed into the laboratory's chemical waste storage area, and properly labelled and marked. Unknown obsolete chemicals should be handled in the same manner as an unknown or unused chemical discussed in the previous section.

Chemicals identified as expired or no longer needed should be:

- removed from ordinary storage;
- placed into the laboratory's chemical waste storage area;
- properly labelled and marked;
- removed from the laboratory within 30-60 days.

In the definition of **expiration date** for a chemical, it is necessary to refer to the 'chemical common sense'. With this approach, a stable inorganic salt, such as magnesium sulfate, can be stored for decades without any loss of the chemical properties, whereas more reactive organic compounds, such as polyolefins, are more prone to degradation in shorter times. However, recovery and purification methods (*e.g.*, distillation, recrystallization, etc.) are very often possible and available, so that the compound can be used again as a fresh reactant.

3.3 Drain disposal

Hazardous chemicals cannot be poured **down the drain**. They must be collected for disposal as hazardous waste.
For instance:

- Any flammable liquids with a flashpoint less than 60°C - including but not limited to any quantity of gasoline, kerosene, naphtha, benzene, toluene, xylene, fuel oil, ethers, ketones, aldehydes, chlorates, perchlorates, bromates, carbides, hydrides, and sulfides. This list does not include aqueous solutions of compounds that have a **flashpoint greater than 60°C**.
- Explosive chemicals.
- Mercury and mercury compounds.
- Radioactive materials.
- Photographic used fixer solutions, unless they are first passed through a silver recovery system.
- Solutions from rinsing containers of highly hazardous waste or any other chemical that would be classified as a hazardous waste.

Indeed, solutions of these compounds, if mixed with the urban sewage stream would cause severe damages or affect negatively to the conventional post-treatment system.

Chemicals that **can be disposed of down the drain**, providing the solution **does not** contain prohibited materials, include:

- Aqueous solutions such as salts or buffer solutions within the pH range of 5.0 to 11.0.
- Chemicals that are water soluble and not hazardous by definition.
- Acids and bases that have been neutralized to fall within the 5.0 to 11.0 pH range.
- Aqueous solutions with <10 µg/L (<10 ppb) ethidium bromide can be discharged to the sewer.
- Aqueous solutions containing >10 µg/L (>10 ppb) ethidium bromide must be chemically treated by filtering through activated charcoal.
- Aqueous solutions containing alcohols at a concentration of 24% by weight or less.
- Aqueous solutions containing formaldehyde at concentrations less than 5% by weight (after pre-treatment with 10% aq. H_2O_2 and Fe)

3.4. In the case of spillage of hazardous chemicals and waste

The size and clean-up difficulty of the spill can be determined by several different factors:

- Physical state of spill material (*i.e*. Solid, Liquid or Gas);

- Quantity of material;
- Hazards of the material (Flammable, Corrosive or Toxic);
- Hazardous Conditions Caused by the spill;
- Contamination of Personnel by the spill.

Any size spill can be cleaned up if the **adequate equipment** is available. If possible, it is advisable to do enough to **prevent progress of spill**. Solids spills can be scooped back into a jar or beaker, while liquids can be absorbed with paper towels, bench coat or cloths to control it.
Vapours produced from spills cause the most relevant hazards, when the leaked compounds are toxic and/or flammable. It must be carefully considered that corrosive solids and liquids may react with the response materials. High vapour pressure values usually are an indication of volatile liquids.

An operator must **never response to unknown spills alone**.

In the case of spills of chemicals in a laboratory, it is very important to have a **Spill Kit** readily available. It is advisable to set up the kit for the specific needs of the laboratory and to tailor the components of the kit according to the most frequent and/or most hazardous materials handled in the laboratory.

Fig. 3.5 Example of spill kit and use of vermiculite clay absorbent granules to prevent leaking and spills

Analogously, it is necessary to take inventory of the kit frequently and replace quickly the used or missing items of the kit. The re-use of absorbent materials found in packages and parcels, in which commercial reactants are shipped, is a convenient and cheap alternative for the set-up of a self-made emergency spill kit.

In most cases, the absorbent materials are made of granules of high specific surface area adsorbent clays, such as vermiculite or sepiolite clays, and possess a very large absorption capability.

For Small Spills

In the case of spills **up to 2.5 L** (maximum flask or bottle), the spilled liquid must be cleaned using the material in the spill kit. Operators must don their personal protective equipment, PPE, that must be suitable for the chemical and physical nature of the compound. The contaminated material is then placed in the spill bag, sealed and identified by a hazardous waste label. After that, the recovered spilled material follows the conventional waste handling and fate for that kind of hazardous materials.

For Larger Spills

In the case of large spills (**more than 2.5 L**), it is important first to contain the spill, if possible and only if it is safe for the operators, then notify the rest of the personnel in the area and evacuate the zone. It is consequently necessary to notify the lab safety officer and the emergency service of the facility the spillage took place in.

In the case of **major accidents** (large fire, broad contamination) and if it happens after business hours, it is necessary to notify the Public Emergencies system (hazmat squad of the fire brigade or an equivalent local public service).

It is never advisable to attempt to stop a **broken gas cylinder**. The most dangerous spill situation is, indeed, a leaking or broken gas cylinder. The gas contained in the cylinder can be either toxic, flammable, corrosive, an asphyxiant or a combination of these. It is necessary initially to evacuate the area, contact the local emergency/safety service, while finding someone who knows what the cylinder contains. It is then advisable to try to isolate the area affected by gas through ventilation controls, fume hoods and securing doors. In this step, the self-protection is of utmost importance. In addition, signage of the hazard is important to control exposure. Solids or viscous liquids can make moving around **slippery** and **dangerous**. The location of the spill can make exiting hazardous. It is, moreover, important not to contaminate clean areas with the spilled material and be sure that fumehoods are running.

The same precautions for handling hazardous chemicals are applied to the handling of chemical waste materials in their containers as well as in the case of minor spillages:

- eye protection;
- lab coats;

- gloves;
- airways protection (when organic volatile vapours are present)
- working safety boots, avoiding any sort of open shoes (slippers or sandals) in hot climates or in summer.

In conclusion, all these handling activities are tuned for small-medium research or academic chemical laboratories. Of course, industrial and technical manufacturing laboratories must follow different and more specific guidelines.
The mastering of best practices in a chemical laboratory need a constant and periodical education, formation and training of new personnel (either permanent or non-permanent staff).

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4. Biological Waste Management

The most important questions to be asked before discharge of any objects or materials from laboratories that deal with potentially infectious microorganisms are:

1. Have the objects or materials been effectively decontaminated or disinfected by an approved procedure?
2. If not, have they been packaged in an approved manner for immediate on site incineration or transfer to another facility with incineration capacity?
3. Does the disposal of the decontaminated objects or materials involve any additional potential hazards, biological or otherwise, to those who carry out the immediate disposal procedures or who might come into contact with discarded items outside the facility?

Biohazardous waste that are generated within a Health Care Facility, HCF, should always follow an appropriate and well-identified stream from their generation point until their final disposal. This stream is composed of several steps that include: *generation*, *segregation*, *collection* and *on-site transportation*, *on-site storage*, *offsite transportation* (optional), *treatment* and *disposal*.
However, in terms of daily use, few contaminated materials will require actual removal from the laboratory or destruction, because part of the equipment like glassware, instruments and laboratory clothing will be reused or recycled. Moreover, in many countries, recycling of potentially contaminated items such as the plastic and metal from syringes/needles is not recommended for the moment due to the absence of availability of appropriate technologies, lack of specific training/awareness as well as adequate management procedures.

The overriding principle is that all infectious materials should be decontaminated, autoclaved or incinerated within the laboratory. Medical activities generate waste that should always be discarded at the point of use by the person who used the item to be disposed of. The quantity of healthcare waste generated should always be minimized and precautions must be taken during their handling. Before producing waste, investigation should be carried out on whether the amount of waste generated could be minimized in order to reduce efforts in subsequent handling, treatment and disposal operations.

4.1 Segregation, minimization and classification

Segregation and Minimization
One of the keys to minimization and effective management of health-care waste, HCW, is segregation (separation) and identification of the waste. Given the fact

that only about 10-25% of the HCW is hazardous, treatment and disposal costs could be widely reduced if proper segregation were carried out. Segregating hazardous from non-hazardous waste also reduces the risks of infecting workers handling HCW. Segregation, consists in separating the different waste streams based on the hazardous properties of the waste, the type of treatment and disposal practices that are applied.

A recommended way of identifying HCW categories is by sorting the waste into colour-coded and well-labelled bags or containers. Segregation should always be the responsibility of the waste producer and should take place as close as possible to where the waste is generated.

All the specific procedures of HCW segregation, packaging and labelling should be explained to the medical and ancillary staff and displayed in each department on charts located on the walls nearby the HCW containers that should be specifically suited for each category of waste. A specific identification and segregation system for infectious materials and their containers should be adopted. Categories should include:

1. Non-contaminated (non-infectious) waste that can be reused or recycled or disposed of as general, "household" waste;
2. Contaminated (infectious) "sharps" – hypodermic needles, scalpels, knives and broken glass; these should always be collected in puncture-proof containers fitted with covers and treated as infectious;
3. Contaminated material for decontamination by autoclaving and thereafter washing and reuse or recycling;
4. Contaminated material for autoclaving and disposal;
5. Contaminated material for direct incineration.

With regards to infectious waste, the most important features of segregation related to the categories established by the United Nations are here listed:

B1 (human anatomical waste): It is primarily for ethical reasons that special requirements must be placed on the management of waste human body parts, organs and tissues. The waste must be collected in appropriate containers or bags as soon as possible at the place where it is generated. It must be kept in tight receptacles and under stable low temperature (5-8°C) conditions when stored temporarily for a prolonged period of time.

B2 (sharps): Sharps require that measures be taken to prevent injury and infection during their handling within and outside of the HCFs. They have to be collected and managed separately from the other categories of HCW: the collection containers (safety boxes) must always be puncture and leak-proof. The storage of sharps to be disposed of should always take place at a location that is accessible only to trained personnel. Once the safety boxes are sealed, they can

be disposed of with the other infectious waste depending on the type of disposal technology that is selected.

B5 (blood and body fluids waste): Special requirements must be imposed on the management of this category of waste from the point of view of infection prevention in and outside the HCFs. Double bags or containers made of strong and leak-proof material are used for the collection of these waste materials.

C1 (infectious waste): Infectious waste must be collected in leak-proof containers carefully sealed and transported to a central storage facility/delivery point in a way that precludes direct contact.

Colour coding system

The most appropriate way of identifying the categories of healthcare waste is by sorting the waste into colour-coded plastic bags or containers. The application of a colour coding system aims at ensuring an immediate and non-equivocal identification of the hazards associated with the type of HCW that is handled or treated. In that respect, the colour coding system should remain simple and be applied uniformly throughout the country.

For example, all special HCW of categories B1, B4, B5, C1, C2 should be placed in yellow containers (preferably yellow polyethylene bags of minimum 300 μm gauge) marked and indicated with the international biohazard symbol. Preferably, the bags should be fixed in bag-holders. If not available, yellow bins could be used.

Black

- non−risk waste of category A
- exceptionally, small quantity of waste of category B1
- pharmaceutical waste of category B3, class B31 only

Yellow

- special waste of categories B1, B2, B4, B5
- infectious waste and highly infectious waste of categories C1 and C2
- radioactive waste of category E

Brown

- pharmaceutical waste of categories B3, classes B32 and B33
- category D such as chemicals, heavy metal waste

Colour coding system for healthcare waste, as from "Preparation of Health Care Waste Management Plan in Sub-Saharan Countries", UN Environmental Programme and World Health Organization, 2004.

In addition to colour coding of waste containers, the following practices are recommended:

- Since costs for safe treatment and disposal of hazardous health-care waste are typically more than 10 times higher than those for general waste, all general, *i.e*. non-hazardous, waste should be handled in the same manner as domestic refuse and collected in black bags.
- HCW of category B2 (sharps) should all be collected together, regardless of whether or not they are contaminated. Containers should be puncture-proof (usually made of metal or high-density plastic) and fitted with covers. They should be rigid and impermeable so that they safely retain not only the sharps but also any residual liquids from syringes. To discourage abuse, containers should be tamper-proof (difficult to open or break) and needles and syringes should be rendered unusable. Where plastic or metal containers are unavailable or too costly, containers made of dense cardboard are recommended; these fold for ease of transport and may be supplied with a plastic lining.
- The safety boxes should always be coloured yellow, marked «Danger! Contaminated sharps» and indicated with the Biohazard symbol. It shall be sealed and disposed of when three-quarters full (Fig. 4.1).

Fig. 4.1. Bags and containers for infectious waste should be marked with the international infectious substance symbol

- No healthcare waste other than sharps should be deposited in sharps containers, as these containers are more expensive than the bags used for other infectious waste.
- Highly infectious waste, such as diagnostic laboratory samples and waste from infectious patients in isolation, should be collected separately and autoclaved at the point of generation. Once disinfected, the waste would leave a medical area in the infectious health-care waste container.
- Containers should be removed when they are three-quarters full. Ideally, they should be made of combustible, non-halogenated plastics.
- Staff should never attempt to correct errors of segregation by removing items from a bag or container after disposal or by placing one bag inside another bag of a different colour. If general and hazardous waste materials are accidentally mixed, the mixture should be treated as hazardous healthcare waste.
- Anatomical waste, particularly recognizable body parts or fetal material, should be handled according to prevailing religious and cultural preferences (most commonly, authorized burial or cremation). In low-resource areas, placentas and other non-recognizable anatomical waste can be disposed of in a pit where it can biodegrade naturally.

Labelling

All waste bags or containers should be labelled with basic information on their content and on the waste producer. This information may be written directly on the bag or container or on pre-printed labels, securely attached.

It is possible to identify two labelling activities inside the laboratories: while the first one is concerned with purely internal activities, the other, in spite of its internal nature, it is oriented toward the “out of house” phase of the waste cycle.

The first activity is represented by the labelling of the first collection of waste, namely the labelling of each single item according to its potential risk of infection. The following table lists the different possible sentences adopted on each container depending on the category of HCW.

B1 - «Danger! Anatomical waste, to be incinerated or deeply buried»
B2 - «Danger! Contaminated sharps, do not open»
B4, B5, C1 - «Danger! Hazardous infectious waste»
C2 - «Danger! Highly infectious waste, to be pre–treated»
B32, B33, D - «Danger! To be discarded by authorized staff only»
E - «Danger! Radioactive waste»

Category Labelling International symbols

The second kind of activity, as previously mentioned is carried out "in house", but it aims at preparing the waste materials for their transportation outside the facility. According to the United Nations recommendations for dangerous substances, the following indications should appear on the label:

- the United Nations substance class, *e.g*. Class 6.2 for infectious waste;
- the United Nations packaging symbol, *e.g*. the international symbol for infectious substances;
- the proper shipping name and the UN number;
- the total quantity (mass or volume) of waste covered by the description;
- the country authorizing the allocation of the label (identified by international code system used on motor vehicles).

It is also recommended that the last two digits of the year of manufacture of the packaging specified by the competent authority are marked on the package, as well as a special code designating the type of packaging. The following additional information should be marked on the label: waste category, date of collection, place in the facility where produced (*e.g*. ward), waste destination.
In case of problems involving questions of liability, full and correct labelling allows the origin of the waste to be traced. Labelling also warns operative staff and the general public of the hazardous nature of the waste. The hazards posed by container contents can be quickly identified in case of accident, enabling emergency services to take appropriate action.

Collection

In order to avoid accumulation of the waste, it must be collected on a regular basis and transported to a central storage area within the HCF before being treated or removed. The collection must follow specific routes through the HCF to reduce the passage of loaded carts through wards and other clean areas.
Great care should be taken when handling HCW. The most important risks are linked with the injuries that sharps can produce. When handling HCW, staff and cleaners should always wear protective clothing including, as minimum, overalls or industrial aprons, boots and heavy duty gloves.
Nursing and other clinical staff should ensure that waste bags are tightly closed or sealed when they are about three-quarters full. Light-gauge bags can be closed by tying the neck, but heavier-gauge bags probably require a plastic sealing tag of the self-locking type. Bags should not be closed by stapling. Sealed sharps containers should be placed in a labelled, yellow infectious health-care waste bag before removal from the facility.

Waste materials should not be allowed to accumulate at the point of production. A routine programme for their collection should be established as part of the

health-care waste management plan. Certain recommendations should be followed by the ancillary workers in charge of waste collection:

- Waste should be collected daily (or as frequently as required) and transported to the designated central storage site.
- No bags should be removed unless they are labelled with their point of production (hospital and ward or department) and contents.
- The bags or containers should be replaced immediately with new ones of the same type.
- A supply of fresh collection bags or containers should be readily available at all locations where waste is produced.

4.2 Transportation and storage

Transportation

Onsite transport should take place during less busy times whenever possible. Set routes should be used to prevent exposure to staff and patients and to minimize the passage of loaded carts through patient care and other clean areas. Depending on the design of the health-care facility, the internal transport of waste should use separate floors, stairways or elevators as far as possible. Regular transport routes and collection times should be fixed and reliable.

Transport staff should wear adequate personal protective equipment, gloves, strong and closed shoes, overalls and masks. Hazardous and non-hazardous waste should always be transported separately. Infectious waste can be transported together with used sharps waste. Infectious waste should not be transported together with other hazardous waste, to prevent the possible spread of infectious agents. Trolleys should be coloured in the appropriate colour code for infectious waste (yellow) and should be labelled with an “Infectious waste” sign.

Healthcare waste should be transported within the hospital or other facility by means of wheeled trolleys, containers, or carts that are not used for any other purpose and meet the following specifications:

- easy to load and unload;
- no sharp edges that could damage waste bags or containers during loading and unloading;
- easy to clean and, if enclosed, fitted with a drainage hole and plug;
- be labelled and dedicated to a particular waste type;
- be easy to push and pull;
- not be too high (to avoid restricting the view of staff transporting waste);
- be secured with a lock (for hazardous waste);
- be appropriately sized according to the volumes of waste generated at a health-care facility.

Waste, especially hazardous waste, should never be transported by hand due to the risk of accident or injury from infectious material or incorrectly disposed sharps that may protrude from a container. The vehicles should be cleaned and disinfected on a daily basis with an appropriate disinfectant. All waste-bag seals should be in place and intact at the end of transportation.

Fig. 4.2. Containers for infectious waste transportation

Storage

HCW are temporarily stored before being treated/disposed of on-site or transported off-site. The storage place must be identified as an infectious waste area by using the biohazard sign. Floors and walls should be sealed or tiled to allow easy disinfection. If present, the storage room should be connected to a special sewage system for infectious facility wastewater. The compacting of untreated infectious waste or waste with a high content of blood or other body fluids destined for offsite disposal (for which there is a risk of spilling) is not permitted. Sharps can be stored without problems, but other infectious waste should be kept cool or refrigerated at a temperature preferably no higher than 3°C to 8°C if stored for more than a week. Unless a refrigerated storage room is available, storage times for infectious waste (*e.g*. the time gap between generation and treatment) should not exceed the following periods:

- Temperate climate: 72 hours in winter, 48 hours in summer.
- Warm climate: 48 hours during the cool season; 24 hours during the hot season.

Non-hazardous HCW should always be stored in a separate location from the infectious/hazardous HCW in order to avoid cross-contamination. A storage facility, sized according to the volume of waste generated as well as the frequency of collection, should not be situated near to food stores or food preparation areas and its access should always be limited to authorized personnel. It should also be

easy to clean, have good lighting and ventilation, and designed to prevent rodents, insects or birds from entering.

Fig. 4.3. Clinical Waste Storage

Off-site transportation

The health-care waste producer is responsible for safe packaging and adequate labelling of waste to be transported off-site and for authorization of its destination. Laboratory personnel must ship infectious substances according to applicable transport regulations. Compliance with the rules will:

1. Reduce the likelihood that packages will be damaged and leak, and thereby
2. Reduce the exposures resulting in possible infections
3. Improve the efficiency of package delivery.

Packaging and labelling should comply with national regulations governing the transport of hazardous waste and with international agreements if waste materials are shipped abroad for treatment. In case there are no such national regulations, responsible authorities may refer to *Recommendations on the transport of dangerous goods*, published by the United Nations.

The packaging should include the following essential elements:

- An inner packaging comprising:
  - watertight primary receptacle of metal or plastics with leak−proof seal (*e.g*. a heat seal, a skirted stopper, or a metal crimp seal);
  - a watertight secondary packaging;
  - absorbent material in sufficient quantity to absorb the entire contents placed between the primary receptacle and the secondary packaging.
- An outer packaging of adequate strength for its capacity, mass, and intended use, and with a minimum external dimension of 100 mm.

- A list of contents should be enclosed between the secondary packaging and the outer packaging. The outer packaging should be appropriately labelled.

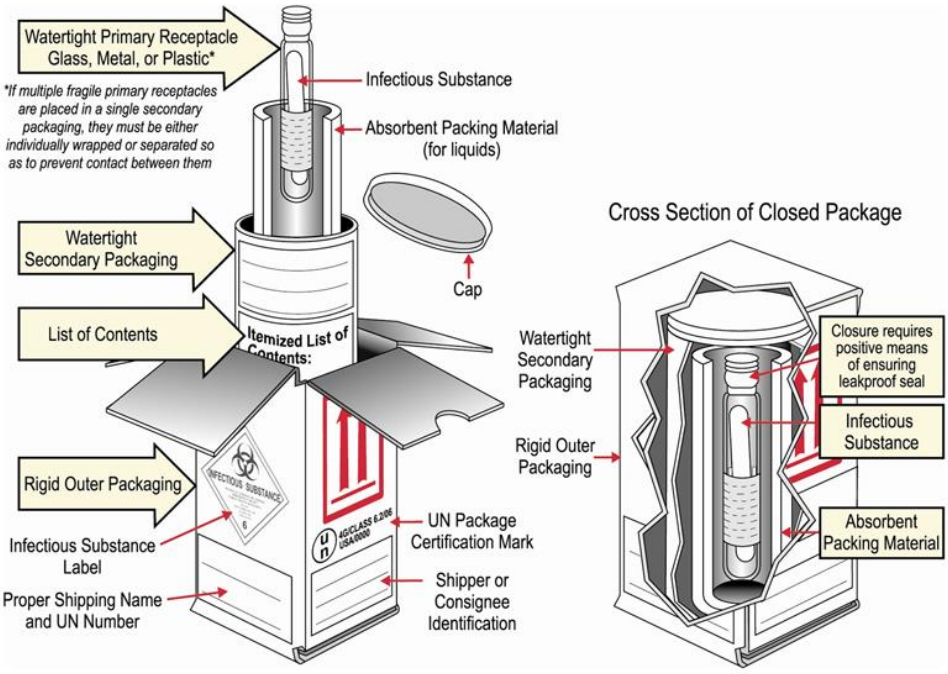

Fig. 4.4. The basic triple packaging system, as from https://www.cdc.gov/smallpox/lab-personnel/specimen-collection/pack-transport.html

4.3 Treatment and disposal

Each class of HCW require specific treatment. However, it is advisable to distinguish three major classes polarizing around 90 % of the biomedical waste production. These major categories could be:

- Waste sharps;
- Infectious and cytotoxic waste;
- Organic waste (blood and body fluid waste, human anatomical waste).

Hazardous/infectious HCW can be treated to reach a level of hazard/infectiousness that is considered as acceptable. Thus, after treatment, they follow the non-risk HCW stream and are disposed of with the general solid waste. They can also be directly disposed of by incineration or in sanitary

landfills. Moreover, hazardous/infectious HCW can be treated on-site (*i.e*. in the HCF itself) or off-site (*i.e*. in another HCF or in a dedicated treatment plant).

Minimal observances for waste treatment and disposal can be summarised as hereafter:

- Ensure that the most hazardous HCW (i.e. sharps) and (highly) infectious waste are properly treated and disposed of in all HCFs of the country;
- Ensure that treatment / disposal options that will be recommended in the National HCWM plan will be homogeneously applied in the country;
- Ensure that the selected options will be compatible with the local operation and maintenance capacities;
- Always select the most environmental friendly options taking into consideration the operation and maintenance costs.

Measures should first be followed to minimize and reuse waste items where it is safe to do so. Where this is not possible, the unusable waste materials should preferably be treated to reduce their potential health or environmental hazard and volume, with remaining residues sent for land disposal to a suitably constructed site. Incineration used to be the method of choice for most hazardous healthcare waste and is still widely used. However, recently developed alternative treatment methods are becoming increasingly popular. The final choice of treatment system should be made carefully, on the basis of various factors, many of which depend on local conditions. Certain treatment options presented in this section may effectively reduce the infectious hazards of health-care waste and prevent scavenging but, at the same time, give rise to other health and environmental hazards In choosing a treatment or disposal method for health-care waste, particularly if there is a risk of toxic emissions or other hazardous consequences, the relative risks, as well as the integration into the overall framework of comprehensive waste strategy, should therefore be carefully evaluated in the light of local circumstances.

Incineration

Incineration is not the same as burning. However, both methods are used for the treatment of hazardous waste. Burning in small-capacity single chamber “incinerators” is a technique often used in HCFs in low-income countries. These installations may nevertheless constitute a serious air pollution hazard to the surrounding area due to the relatively low operation temperatures and the lack of emission control systems. If biomedical and health-care waste are treated with single chamber “incinerators”, waste fractions such as cytotoxic drugs, chemicals, halogenated materials or waste with a high content of heavy metals (batteries, broken mercury thermometers, etc.) *should not be treated* with this type of system).

Incineration is a high-temperature dry oxidation process that reduces organic and combustible waste to inorganic, incombustible matter and results in a very significant reduction of waste volume and weight. The procedure has the advantage of reducing significantly the volume and weight of the waste treated and it represents an alternative to autoclaving only if the incinerator is under laboratory control. Nevertheless it requires skilled operators, extensive flue gas emission control systems and, frequently, imported spare parts. Materials for incineration, even with prior decontamination, should be transported to the incinerator in bags, preferably plastic. Incinerator attendants should receive proper instructions about loading and temperature control. It should also be noted that the efficient operation of an incinerator depends heavily on the right mix of materials in the waste being treated.

Steam treatment technologies

Autoclaves are capable of treating a range of infectious waste, including cultures and stocks, sharps, materials contaminated with blood and limited amounts of fluids, isolation and surgery waste, laboratory waste (excluding chemical waste). With sufficient time and temperature, it is technically possible to treat small quantities of human tissue, but ethical, legal, cultural, religious and other considerations may preclude their treatment. Autoclaves are generally not used for large anatomical remains (body parts), because it is difficult to determine beforehand the time and temperature parameters needed to allow full penetration of heat to the centre of the body part.

An autoclave consists of a metal vessel designed to withstand high pressures, with a sealed door and an arrangement of pipes and valves through which steam is introduced into, and removed from, the vessel. Some autoclaves are designed with a steam jacket surrounding the vessel; steam is introduced into both the outside jacket and the inside chamber. Heating the outside jacket reduces condensation on the inside chamber wall and allows the use of steam at lower temperatures. An autoclave without a steam jacket, sometimes called a “retort”, is commonly found in large-scale applications and is cheaper to construct.

Air is an effective insulator and a principal factor in determining the efficiency of steam treatment. Removal of air from the autoclave is essential to ensure penetration of heat into the waste. Waste-treatment autoclaves must treat the air that is removed at the start of the process to prevent the release of pathogenic aerosols. This is usually done by treating the air with steam or passing it through a high-efficiency particulate air, HEPA, filter before it is released.

Consequently, autoclaves can be subcategorized according to the method of air removal. The three common types are:

- gravity-displacement autoclaves
- pre-vacuum or high-vacuum autoclaves

- pressure pulse autoclaves.

Since autoclaves must be able to withstand repeated build-up and release of steam pressures, their construction materials, engineering design, fabrication, accuracy of pressure and temperature sensors, and testing must meet basic requirements to operate safely.

For waste treatment, autoclaves should be rated to operate between 1 and 2 bar gauge pressure or higher. Waste-treatment autoclaves can range in size from about 20 litres to more than 20'000 litres. Low-heat thermal processes produce significantly less air pollution emissions than high-heat thermal processes. Consequently, there are no specific pollutant emission limits for autoclaves and other steam treatment systems.

- **Waste collection**: infectious waste bags are placed in a metal cart or bin. The cart or bin should be lined with a plastic liner to prevent waste from sticking to the sides of the container.
- **Pre-heating** (for autoclaves with steam jackets): steam is introduced into the outside jacket of the autoclave.
- **Waste Loading**: the metal cart or bin is loaded into the autoclave chamber. With every load, a colour− changing indicator is attached to the outer surface of the waste bag in the middle of the waste load to monitor treatment. The entry (or charging) door is closed, sealing the chamber.
- **Air evacuation**: air is removed through gravity displacement, pre−vacuuming or pulse vacuuming.
- **Steam treatment**: steam is introduced into the chamber until the required pressure or temperature is reached. Additional steam is automatically fed into the chamber to maintain the temperature and pressure for a set time period. Pressure pulsing autoclaves vary the pressure according to a set process cycle.
- **Steam discharge**: steam is vented from the chamber, usually through a condenser, to reduce the pressure and temperature. In some systems, a post−vacuum cycle is used to remove residual steam and to dry the waste.
- **Unloading**: usually, additional time is provided to allow the waste to cool down further, after which the treated waste is removed and the indicator strip is checked. The process is repeated if the colour change on the indicator shows that the treatment cycle was insufficient.
- **Documentation**: a written log is maintained to record the date, time and operator name; type and approximate amount of waste treated; and post−treatment confirmation results from any automated equipment recording or temperature−pressure monitoring indicator, such as the indicator strip.
- **Mechanical treatment**: If desired, the treated waste may be fed into a shredder or compactor before disposal in a landfill.

Typical operation conditions for an autoclave for healthcare waste treatment

Microwave irradiation

Irradiation treatment encompasses designs using irradiation from electron beams, cobalt-60 radioisotope or ultraviolet sources. Microwave technology is essentially a steam-based process where treatment occurs through the action of moist heat and steam generated by microwave energy. Water contained in the waste is rapidly heated by microwave energy at a frequency of about 2450 MHz and a wavelength of 12.24 cm. In general, microwave-treatment systems consist of a treatment area or chamber into which microwave energy is directed from a microwave generator (magnetron).

Generally, 2 to 6 magnetrons are used with an output of about 1.2 kW each. Some systems are designed as batch processes and others are semi-continuous.

Typical batch systems are designed to handle 30 to 100 litres of waste. Some units require reusable, fully enclosed, microwavable containers. The systems may have multiple programmable cycles corresponding to different treatment temperatures or levels of disinfection. A cycle may range from 30 min to 1 h.

The types of waste commonly treated in microwave systems are identical to those treated in autoclaves: cultures and stocks, sharps, materials contaminated with blood and body fluids, isolation and surgery waste and laboratory waste (excluding chemical waste).

Volatile and semivolatile organic compounds, chemotherapeutic waste, mercury, other hazardous chemical waste and radiological waste should not be treated in a microwave. A fully enclosed microwave unit can be installed in an open area and, with a HEPA filter to prevent the release of aerosols during the feed process, odour is somewhat reduced, except in the immediate vicinity of the microwave unit.

The HCW passes through a preparative process which may include segregation to remove undesirable material before it is shredded and then eventually humidified prior to being treated in the irradiation chamber. At the end, the waste goes through a compactor before being disposed of.

Similar to the autoclaving technique, the output from a microwave facility is considered non-hazardous and can be land-filled together with municipal waste. Since electricity is the main source of energy for operating this technology, gas emissions are also minimal compared to incineration or even autoclaving, which can require the combustion of fuel for the generation of steam.

Dry-heat treatment technologies

This concept of dry-heat treatment has been applied to treatment of infectious health waste more recently. In dry-heat processes, heat is applied without adding steam or water. Instead, the waste is heated by conduction, natural or forced convection, or thermal radiation. In forced convection heating, air heated by

resistance heaters or natural gas is circulated around the waste in the chamber. In some technologies, the hot walls of the chamber heat the waste through conduction and natural convection. Other technologies use radiant heating by means of infrared or quartz heaters. As a general observation, dry-heat processes use higher temperatures and longer exposure times than steam-based processes. They are not commonly used in large-scale facilities and usually treat only small volumes. *Bacillus atrophaeus* spores are known to be resistant to dry heat and are commonly used as a microbiological indicator to measure the effectiveness of dry-heat technologies.

Fig. 4.5. Medical waste autoclave

Fig. 4.6. Medical waste incinerator

Disposal

In all waste systems, the removal of the remaining health-care waste materials after minimization or treatment will require access to land for final disposal. The disposal of laboratory and medical waste is subject to various regional, national

and international regulations, and the latest versions of such relevant documents must be consulted before designing and implementing a programme for handling, transportation and disposal of biohazardous waste. In general, waste materials that have been processed through one of the above mentioned treatment methods, lose their hazardous characteristics. For example, ashes resulting from the incineration may be handled as normal domestic waste and removed by local authorities. Autoclaved waste may be disposed of by off-site incineration or in licensed landfill sites. On the contrary, untreated waste shall not be land-fill disposed, unless special precautions are taken.
The alternative is often an accumulation of health-care waste at HCFs where it is openly burnt or spread indiscriminately around the facility's grounds. This constitutes a far higher risk of transmission of infection than controlled disposal in a land disposal site, even if the land disposal site is not designed to the precise standards used in higher income places.

There are two distinct types of waste disposal to land:

- **Uncontrolled dumping** is characterized by the scattered, uncontrolled deposit of waste at a site. It is a practice that almost always leads to acute pollution problems, fires, higher risks of disease transmission and open access to scavengers and animals. Health-care waste should not be deposited on or around uncontrolled dumps. The risk to people and animals coming into contact with infectious pathogens or hazardous materials is obvious, with the further risk of subsequent disease transmission through direct contact, wounds, inhalation or ingestion, as well as indirectly through the food chain or a pathogenic host species.
- **Controlled landfilling** represents various types of disposal to land characterized by better operating practices and design improvements to reduce health and environmental impacts. The first step to improvement is "controlled dumping", where small improvements can restrict environmental consequences and physical access to waste. This is followed by "engineered landfill" where increasing standards of engineering are used to improve geological isolation of waste from the environment and to allow waste to be covered daily. Disposing of certain types of healthcare waste (for example biohazardous waste) in engineered landfills is possible within the constraints of local regulations. A well-engineered landfill is designed to minimize contamination of soil, surface water and groundwater; limit atmospheric releases and odours; block access to waste by pests and vectors; and prevent contact with the public. Where skills and resources are available, still higher standards of site preparation are possible to achieve a "sanitary landfill", with trained staff and specialized equipment present onsite to manage operations.
- In less developed areas, where a municipality or health-care facility lacks the means to treat waste before disposal, the direct use of a landfill is likely to be

required for much of the material produced. Land disposal of untreated HCW is not recommended and should only be used as a last resort option. If a municipality or medical authority genuinely lacks the means to treat waste before disposal, the use of a landfill has to be regarded as an acceptable disposal route. Allowing healthcare waste to accumulate at hospitals or elsewhere constitutes a far higher risk of the transmission of infection than careful disposal in a municipal landfill, even if the site is not designed to the standard used in higher-income countries. The primary objections to landfill disposal of hazardous health-care waste, especially untreated waste, may be cultural or religious or based on a perceived risk of the release of pathogens to air and water or on the risk of access by scavengers.

Safe burial on HCF premises

Minimal approaches to healthcare waste management need to be used in remote healthcare facilities and underdeveloped areas. In addition, minimal practices may also be necessary in temporary refugee encampments and areas experiencing exceptional hardship. Consequently, the safe burial of waste on hospital premises may be the only viable option available at that time. Even in these difficult circumstances, the HCF management can establish the following basic principles:

- Access to the disposal site should be restricted to authorized personnel only.
- The burial site should be lined with a material of low permeability, such as clay, dung and river silt, if available, to prevent pollution of shallow groundwater and nearby wells.
- New water wells should not be dug near the disposal pit.
- Only infectious health-care waste should be buried (if general hospital waste were also buried on the premises, available space would be quickly filled).
- Larger quantities (>1 kg) of chemical waste should not be buried at one time; however, burying small quantities occasionally is less likely to create adverse pollution.

The burial site should be managed as a landfill, with each layer of waste covered by a layer of soil to prevent odours and contact with the decomposing waste, and to deter rodents and insects. Alternatively, a specially constructed burial pit can be used. Ideally it should be lined with a material of low permeability such as clay to prevent pollution of shallow groundwater and have a fence around it to prevent scavengers accessing the waste. HCW should be covered immediately with a layer of soil after each load. For added health protection and odour suppression, it is suggested that lime be spread over each waste load. Once the pit is filled, it should be sealed off.

Treatment/disposal method	Advantages	Disadvantages
Dual-chamber Starved-air incinerators	Very high disinfection efficiency Adequate for all infectious waste	Incomplete destruction of atmospheric pollutants Relatively high investment and operating costs
Small-scale incinerators	Good disinfection efficiency Drastic reduction of weight and volume of waste. Residues may be disposed of in landfills. No need for highly trained operators. Relatively low investment and operating cost	Significant emissions of atmospheric pollutants. Need for periodic removal of slag and soot. Inefficiency in destroying temperature-resistant chemicals and drugs such as cytotoxic.
Drum or brick incinerator	Drastic reduction of weight and volume of the waste Very low investment and operating costs.	Destroy only 99% of microorganisms No destruction of many chemicals and pharmaceuticals Massive emission of black smoke, fly ash, toxic flue gas and odours.
Steam treatment technologies	Environmentally sound Drastic reduction in waste volume Relatively low investment and operating cost	Shredders are subject to frequent breakdowns and poor functioning Requires qualified technicians Inadequate for anatomical, pharmaceutical and chemical waste as well as waste that is not readily steam−permeable
Microwave irradiation	Good disinfection efficiency under appropriate operating conditions Drastic reduction in waste volume Environmentally sound	Relative high investment and operating cost. Potential operation and maintenance problems
Encapsulation	Simple, low−cost and safe It may also be applied to pharmaceuticals	Not recommended for non−sharp infectious waste
Safe burying	Low costs Relatively safe if access to site is restricted and where natural infiltration is limited	Safe only if access to site is limited and certain precaution are taken

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5. Identification, Classification and Labelling of Hazardous Chemical Waste

5.1. The Globally Harmonized System (GHS)

Mitigation of risks, generated by improper handling of hazardous materials, can be achieved by a careful identification of the **type of hazard**, thanks to a proper labelling of the substance or waste.
Considering how difficult can be a common hazard identification in different Countries, the need of a unique classification system has been perceived in worldwide in manufacturers and trade organizations. It has been necessary to adopt a common language and list of hazards, in order to harmonize the trade and the movement of materials among borders.

The **United Nations Globally Harmonized System, GHS, for classification and labelling of chemicals**, in its eighth version, issued in year 2019, is a system for **standardizing chemical classification and labelling for world-wide implementation**.
The GHS is a common and coherent approach to defining and classifying hazards and communicating information on labels and safety data sheets, SDS. The target audiences of GHS include **workers, consumers, transport workers and emergency responders**. Such system provides the underlying infrastructure for establishment of national, comprehensive chemical safety programs.

Several factors prompted the United Nations to implement the GHS. First of all, the need to avoid differences among the national, regional and international, and wide disparity in available data among countries. Moreover, no country has the ability to identify and specifically regulate every hazardous chemical product. For example, in the USA, there is an estimation of 650,000 products with hazardous characteristics. In addition, the adoption of requirements for information to accompany the product helps address protection needs.

Many different countries came up with the same conclusions about using information dissemination as a regulatory means to address chemical hazards: while **similar**, they are **different enough** to require **multiple labels** and safety data sheets for the same product. For instance, a product may be considered flammable or toxic in one country, but not in another to which it is being shipped.

In the area of trade, the need to comply with multiple regulations regarding hazard classification and labelling represents a **remarkable cost** and it is highly **time consuming**. For these reasons, a number of small and medium enterprises are effectively precluded from international trade in chemicals, as a consequence of the regulatory burden of compliance.

The primary benefit of GHS is to ensure with adequate, reliable, practical and comprehensive information on hazards of chemicals to governments, international organizations, chemical manufacturers, and any person who happens to be in touch with chemicals. The system provides benefits to Government in terms of fewer chemical accidents, incidents, lower health care costs, improved protection of workers and public, thanks to a reliable information, greater awareness on hazards for safer use at work places and at home.

The principles of harmonization

The entire process of development of a harmonized system that can be used globally has been managed by the Inter-Organization Programme for the Sound Management of Chemicals (IOMC), the **Coordinating Group for Harmonization of Chemical Classification Systems** (CG/HCCS), and all the technical work has been divided among technical focal points, such as the Organization for Economic Cooperation and Development (OECD), the UN Committee of Experts for the Transport of Dangerous Goods (UNCETDS), the International Labour Organization (ILO) (Figure 5.1).

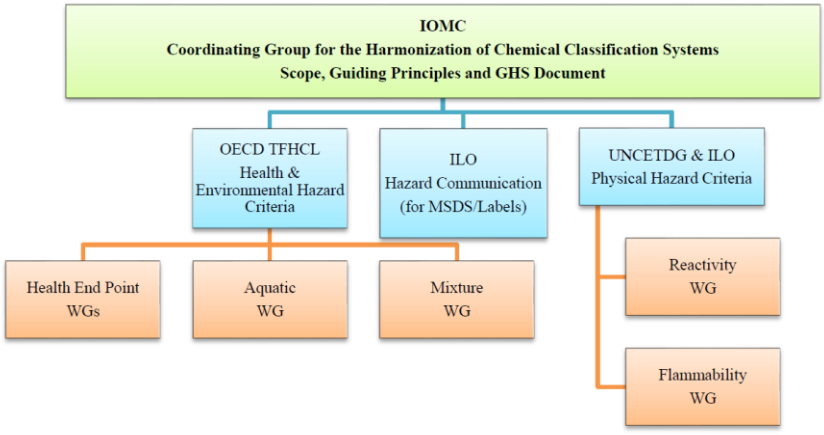


Figure 5.1 Administrative Hierarchy of GHS

The GHS covers **all hazardous chemical substances**, dilute solutions and mixtures. **Exposure** is the key of the evaluation. For instance, pharmaceuticals, food

additives, cosmetics and pesticide residues in food will not be covered at the point of intentional intake, but will be covered where **workers may be exposed**, and in **transport**.

The **implementation of GHS** takes place in two different timeframes: in **Europe**, it was adopted in the new EU Classification, Labelling and Packaging (CLP) since December 1st 2010, for pure compounds, and it will be used from June 1st, 2015 for mixtures. In the USA, it is effective only in part, starting from March 26th, 2012, with a built-in transition period and the fully effective date of June 1st, 2016.

The **pillars of GHS** are the **Classification Criteria**, valid for health and environmental hazards, physical hazards and mixtures, and the **Hazard Communication**, through labels and **Safety Data Sheets**.

The physical, health and environmental hazards consider, for each single chemical are:

Physical Hazards(17 classes):

1. Explosives
2. Flammable Gases
3. Aerosols
4. Oxidizing Gases
5. Gases Under Pressure
6. Flammable Liquids
7. Flammable Solids
8. Self-Reactive Substances
9. Pyrophoric Liquids
10. Pyrophoric Solids
11. Self-Heating Substances
12. Substances which, in contact with water emit flammable gases
13. Oxidizing Liquids
14. Oxidizing Solids
15. Organic Peroxides
16. Corrosive to Metals
17. Desensitized explosives

Health Hazards(10 classes):

1. Acute Toxicity (Oral/Dermal/Inhalation)
2. Skin Corrosion/Irritation
3. Serious Eye Damage/Eye Irritation
4. Respiratory or Skin Sensitization
5. Germ Cell Mutagenicity
6. Carcinogenicity
7. Reproductive Toxicology

8. Target Organ Systemic Toxicity - Single Exposure
9. Target Organ Systemic Toxicity - Repeated Exposure
10. Aspiration Toxicity

Environmental Hazards(2 classes):

1. Hazardous to Aquatic Environment (Acute/Chronic)
2. Hazardous to the Ozone Layer
3. the Acute Toxicity;
4. Skin Corrosion/Irritation properties;
5. Serious Eye Damage/Eye Irritation;
6. Respiratory or Skin Sensitization;
7. Germ Cell Mutagenicity;
8. Carcinogenicity;
9. Reproductive Toxicity;
10. Target Organ Systemic Toxicity, via single and/or repeated dose;
11. Hazardous characteristics to the aquatic environment.

In the case of **mixtures**, when available, it is strongly advisable to use test data for the mixture itself or, as a second choice, to use bridging principles, if applicable. For health and environmental hazards, it is possible to estimate the hazards based on the **known ingredient** information.
Definitions, test methods and classification criteria for transport were used as a basis for the work since they were already harmonized.

5.2. Labelling, pictograms and Safety Data Sheet (SDS)

Communications relating to chemicals being handled during product life cycle are emphasized and GHS emphasizes especially relating to development guideline of labels, symbols and material data safety sheets.

The **comprehensibility** was the leading guideline:

- Information has to be convoyed in **more than one way**.
- The comprehensibility of the components of the system should take account of **existing studies** and evidence gained from **testing**.
- The phrases used to indicate the degree (severity) of hazard should be **consistent** across different hazard types.

For labelling, the Working Group identified about **35 different types of information** that are currently required on labels by different systems. In order to harmonize, key information elements needed to be identified. Additional harmonization may occur on other elements in time, in particular for **precautionary statements**.

The labelling contains the following key elements:

- Product identifier
- Supplier identifier
- Chemical identity
- Hazard pictograms
- Signal words
- Hazard statements
- Precautionary information

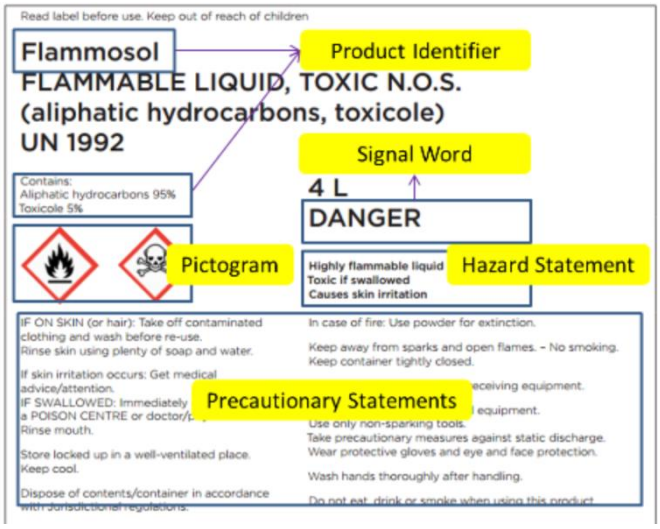


Figure 5.2 A sample GHS label

Among these, hazard pictograms, signal words and hazard statements are standardized.

For transport, pictograms have the background and symbol colours currently used.

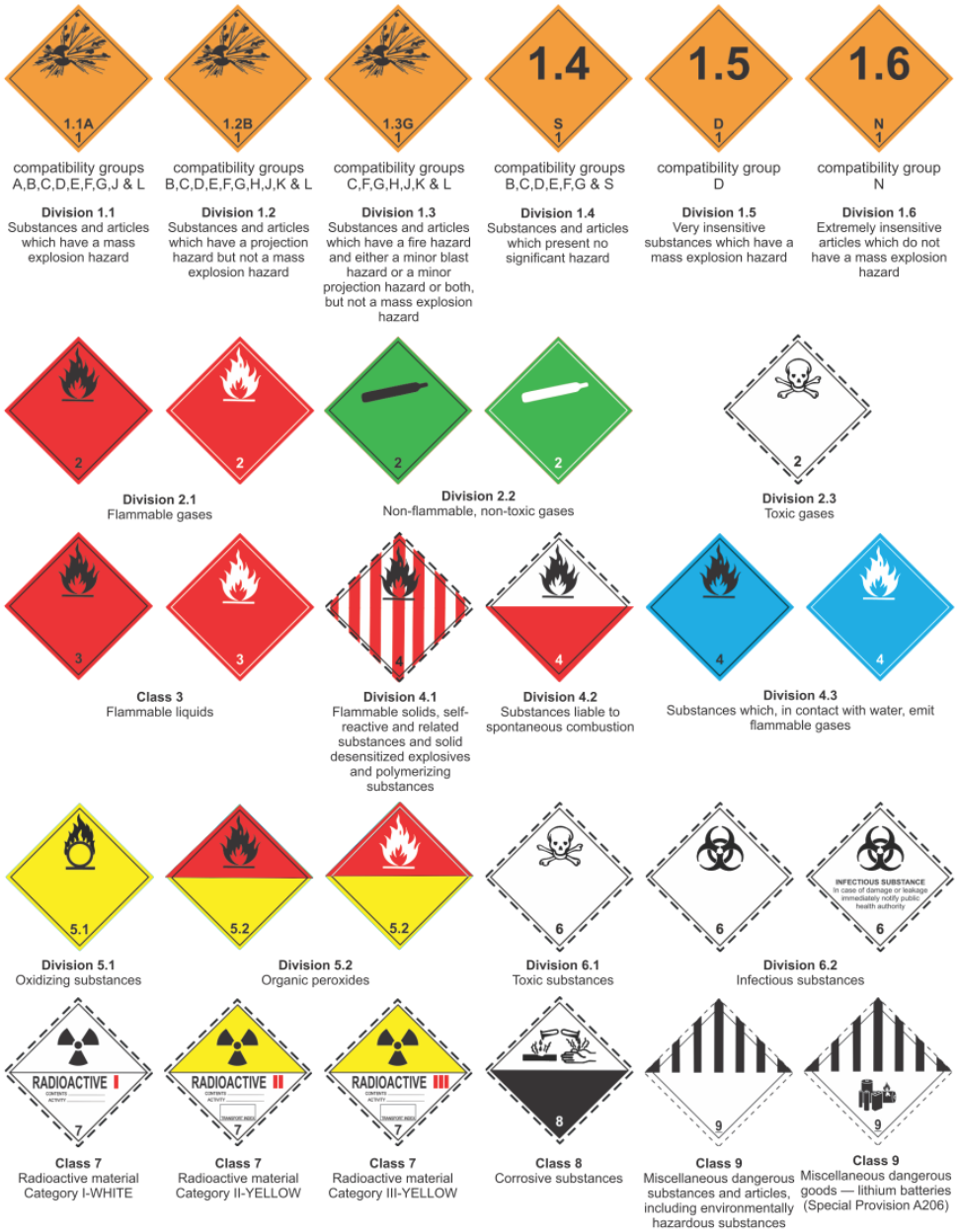


Figure 5.3 GHS Transport Pictograms

For other sectors, pictograms have a **black symbol** on a **white background** with a **red diamond frame**.

Figure 5.4 GHS Pictograms

Where a transport pictogram appears, the GHS pictogram for the same hazard should not appear.

On containers

On shipping boxes

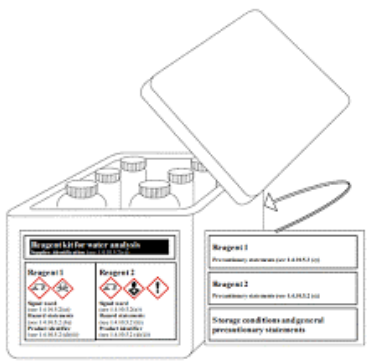
As an example, the following GHS Pictogram is used to describe:

- Carcinogenicity
- Mutagenicity
- Reproductive toxicity
- Respiratory sensitizer compound
- Target organ toxicity
- Aspiration toxicity
- Germ cell mutagenicity

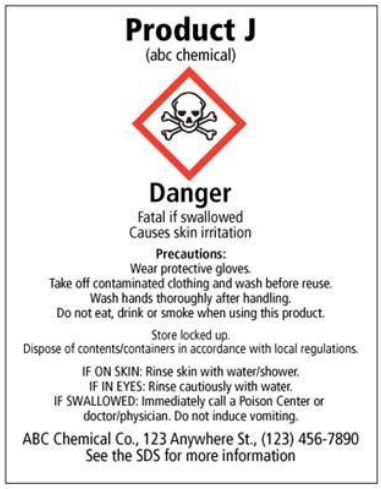
The following examples convey the meaning of precautionary statement P102 “Keep out of reach of children” and may be used to convey information in more than one way according to sections 1.4.4.1 (a) and A.3.3.1.8. One pictogram is from International Association for Soaps, Detergents and Maintenance Products (AISE) while the other one is from Japan Soap and Detergent Association (JSDA). It will be important for the labelling of chemical products supplied to the public.

AISE JSDA

A new labelling system for sets or kits has been introduced. Generally, a set or kit contains two or more small removable inner containers. Each inner container contains different products which can be hazardous or not hazardous substances or mixtures. This new example illustrates ways to label sets or kits where the manufacturer/supplier or competent authority has determined there is insufficient space to place together on each inner container within the kit.



In general, each container must be labelled, tagged or marked. The warning can be a message, words, pictures or symbols. The labels must be written in local language and/or in English and prominently displayed.



Signal words are used: Danger or Hazard, to emphasize the risk and discriminate between levels of hazard. There is indeed a single harmonized hazard statement for each level of hazard within each hazard class. For instance, for flammable liquids:

- *Category 1:* Extremely flammable liquid and vapour
- *Category 2:* Highly flammable liquid and vapour
- *Category 3:* Flammable liquid and vapour
- *Category 4:* Combustible liquid.

Other examples of signal words with the subsequent explanation of the hazard, are as follows:

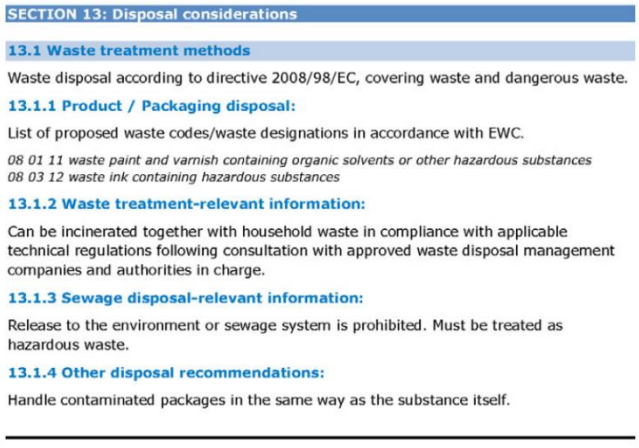
- **Pyrophoric Gases**
  - Signal Word: Danger
  - Hazard Statement: “Catches fire spontaneously if exposed to air”
- **Simple Asphyxiants**
  - Signal Word: Warning
  - Hazard Statement: “May displace oxygen and cause rapid suffocation”
- **Combustible Dusts**
  - Signal Word: Warning
  - Hazard Statement: “May form combustible dust concentrations in the air”

GHS label should include appropriate **precautionary information**. The GHS document includes examples of precautionary statements which can be used. The intent is to harmonize precautionary statements in the future.
This means that the harmonization is still in progress.

Safety Data Sheets, **SDS**, follow each chemical or each hazardous material and the core of such document, covers **16 headings**:

1. Identification
2. Hazard(s) identification
3. Composition/information on ingredients
4. First Aid Measures
5. Fire-fighting measures
6. Accidental release measures
7. Handling and Storage Conditions
8. Exposure control/personal protection
9. Physical and Chemical properties
10. Stability and reactivity
11. Toxicological information
12. Ecological information
13. Disposal considerations
14. Transport information
15. Regulatory information
16. Other Information

It is worth highlighting that, on **point 13**, SDS includes the **description of waste residues** and information on their **safe handling** and **methods of disposal**, including the disposal of any contaminated packaging (see Fig. 5.5).



SECTION 13: Disposal considerations

13.1 Waste treatment methods

Waste disposal according to directive 2008/98/EC, covering waste and dangerous waste.

13.1.1 Product / Packaging disposal:

List of proposed waste codes/waste designations in accordance with EWC.

08 01 11 waste paint and varnish containing organic solvents or other hazardous substances
08 03 12 waste ink containing hazardous substances

13.1.2 Waste treatment-relevant information:

Can be incinerated together with household waste in compliance with applicable technical regulations following consultation with approved waste disposal management companies and authorities in charge.

13.1.3 Sewage disposal-relevant information:

Release to the environment or sewage system is prohibited. Must be treated as hazardous waste.

13.1.4 Other disposal recommendations:

Handle contaminated packages in the same way as the substance itself.

Figure 5.5 Sections 13, SDS

Safety Data Sheets are the best available source of information in case of incidents or accidents, for first responders and rescuers.
Safety data sheet must always be readily accessible to employees during their work shift and kept in a centralized location.

The continuous update of the Safety Data Sheets is responsibility of the Quality Manager or the Safety Manager, according to the company or the institution the laboratory is located in.

In summary, the path towards GHS has been a long and complicated process. Some elements still need complete harmonization. It is being adopted by countries around the world and will achieve the projected benefits for safety, security, protection and trade.

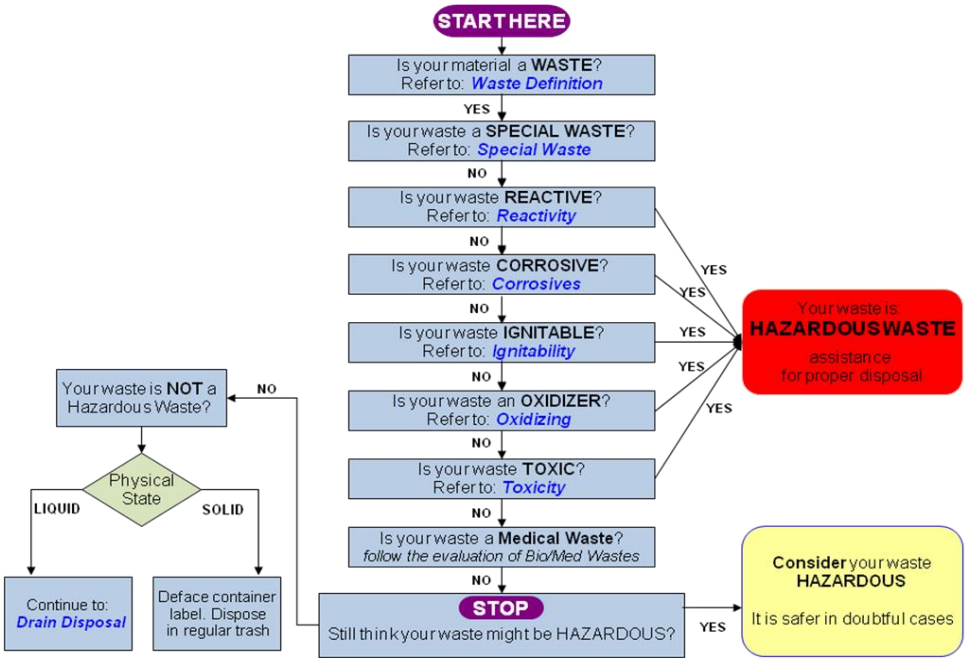
5.3. Hazardous waste? How we classify it in the laboratory?

The term 'waste' is defined as "any substance or object which the holder discards or intends or is required to discard". The following pages present a flowchart that can be a useful first approach to new classes of known / unknown waste. Such scheme is particularly tailored for the waste streams found in research chemical / scientific / hospital laboratories or in small industrial research and development laboratories. On the other hand, it is not suitable for a proper classification of waste streams in large industrial production facilities.

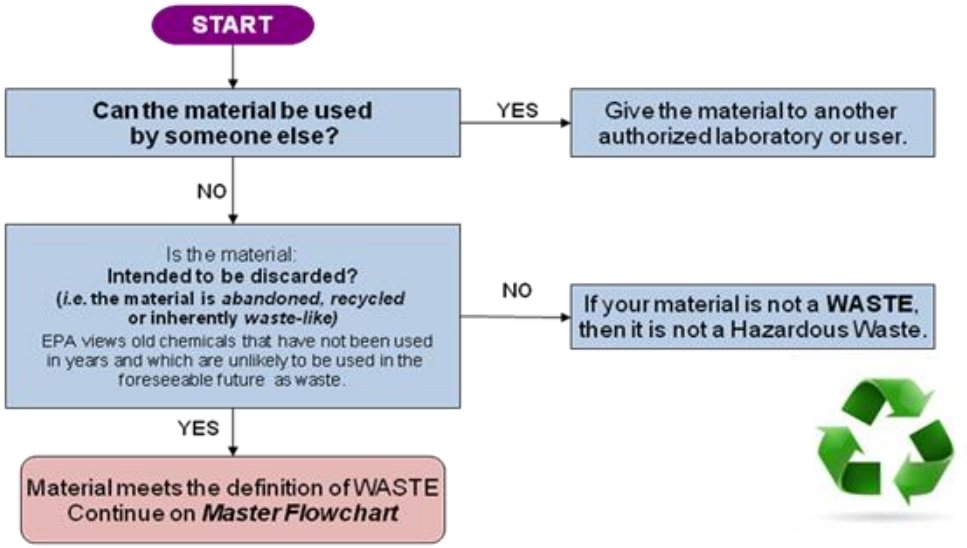
The flowchart suggests how to classify the waste, not how to treat or minimize their hazardous effects.

Starting from a master flowchart, a series of sub-flowchart are directly connected to it, in order to cover at best all the possibilities found in everyday laboratory management.

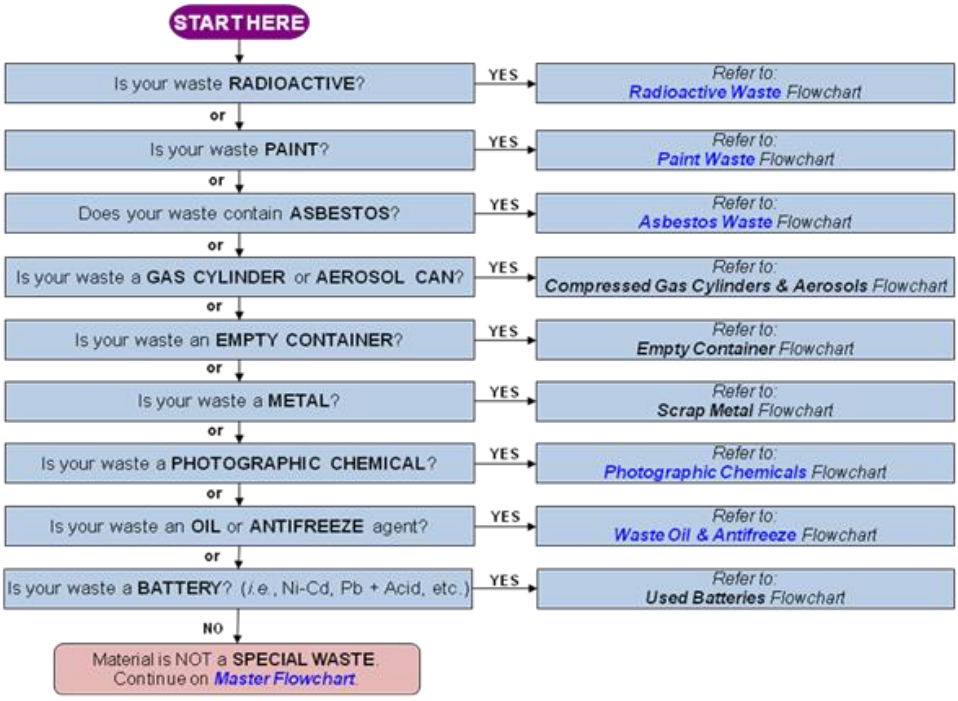
Master Flowchart



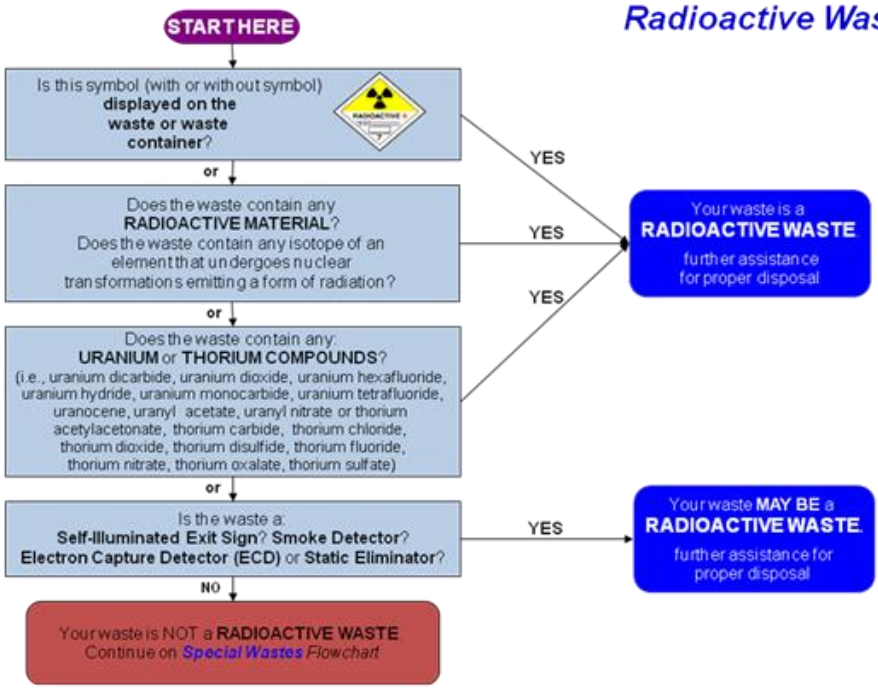
Waste Definition

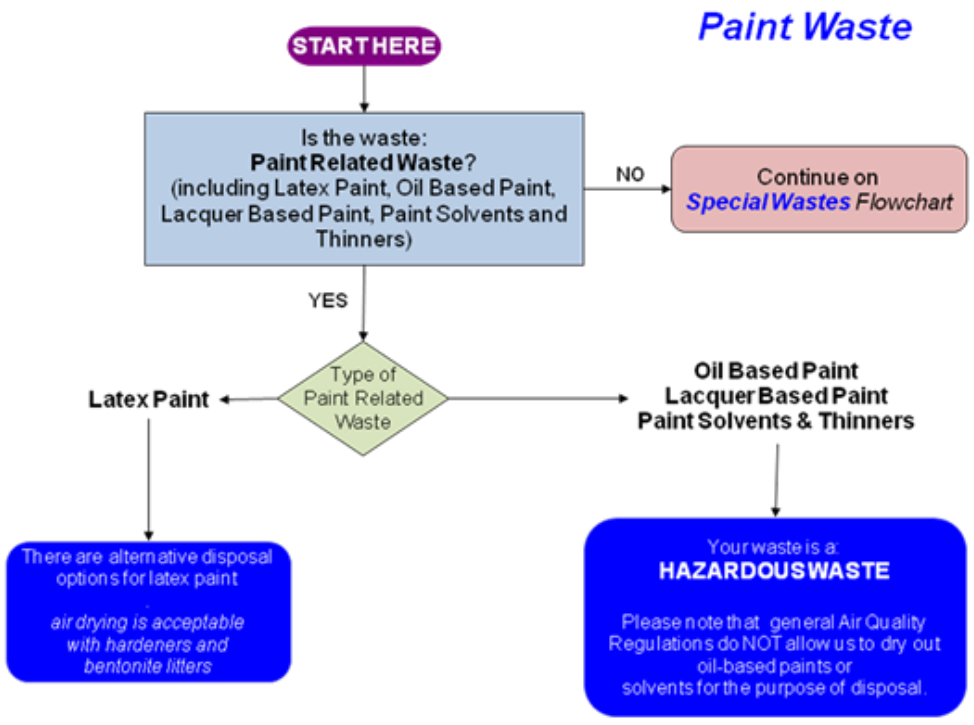


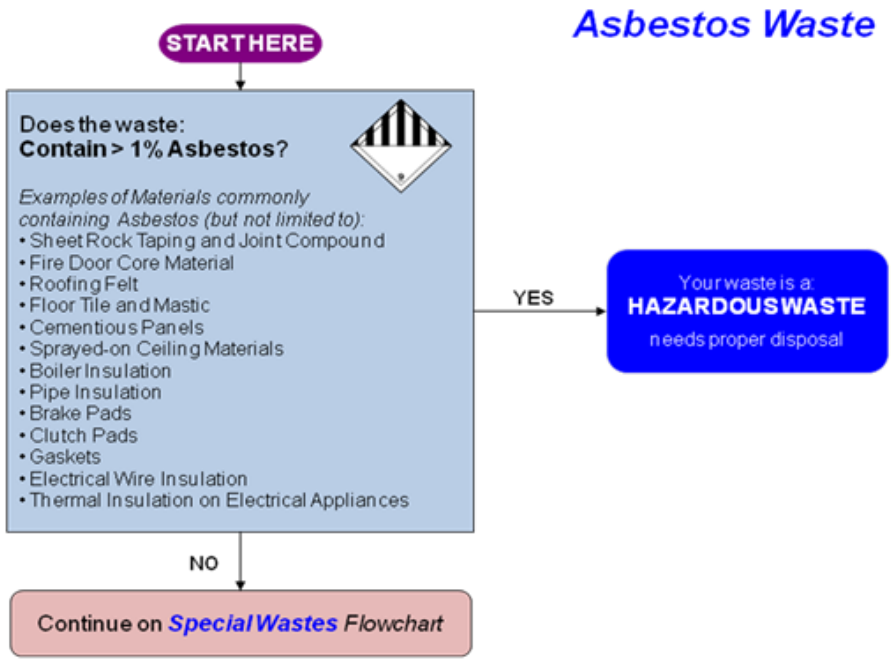
Special Waste

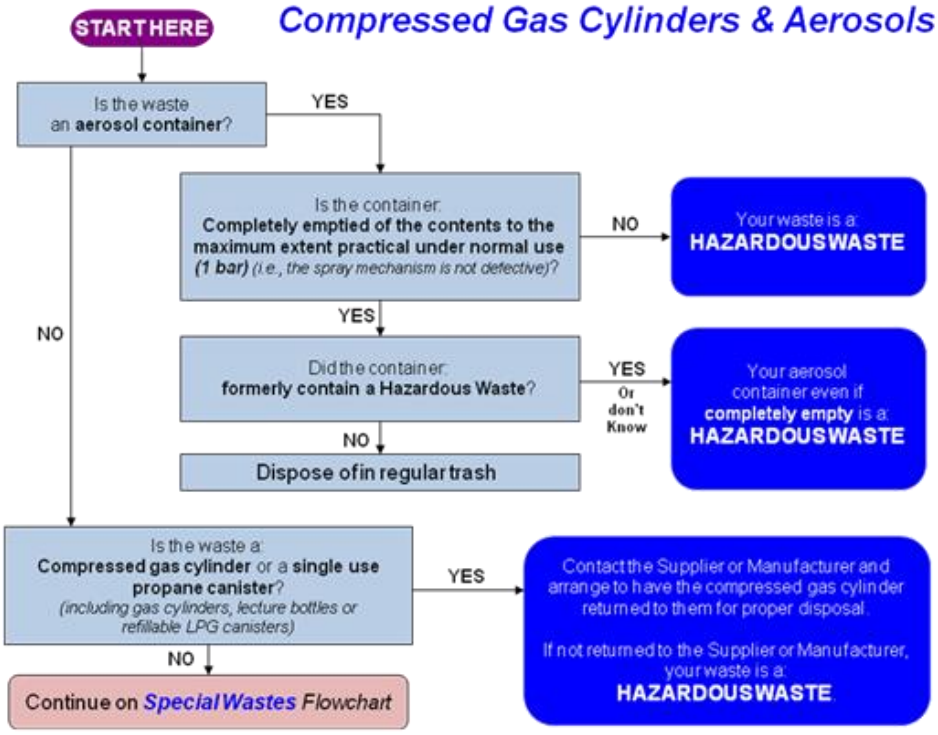


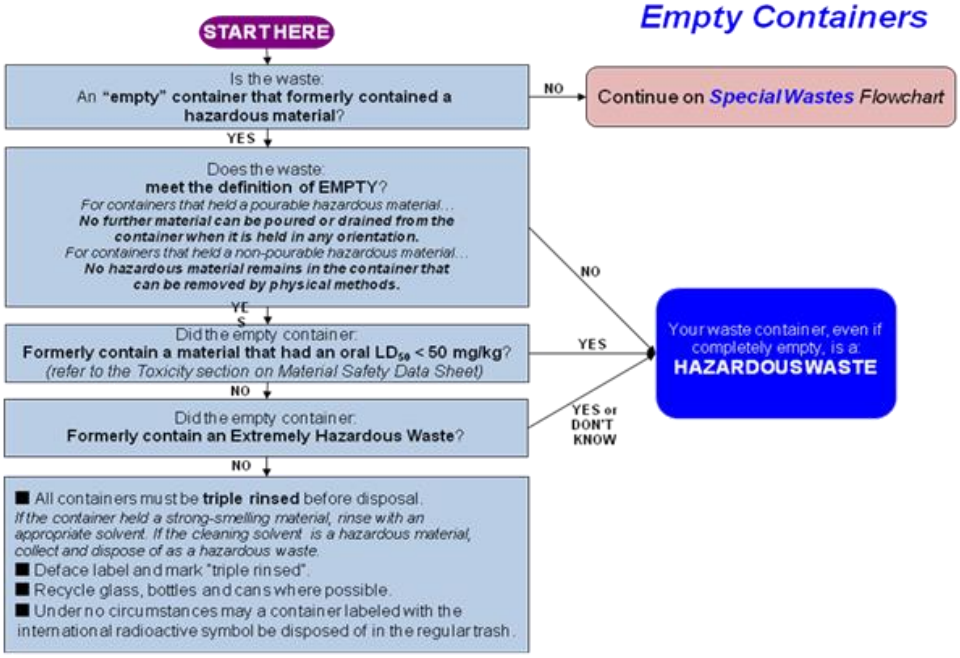
Radioactive Waste

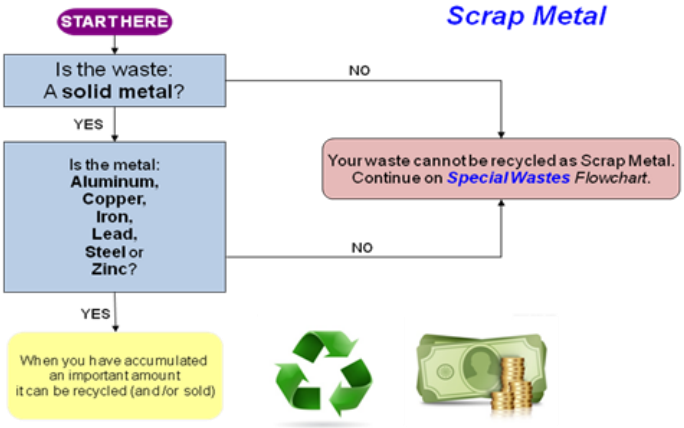


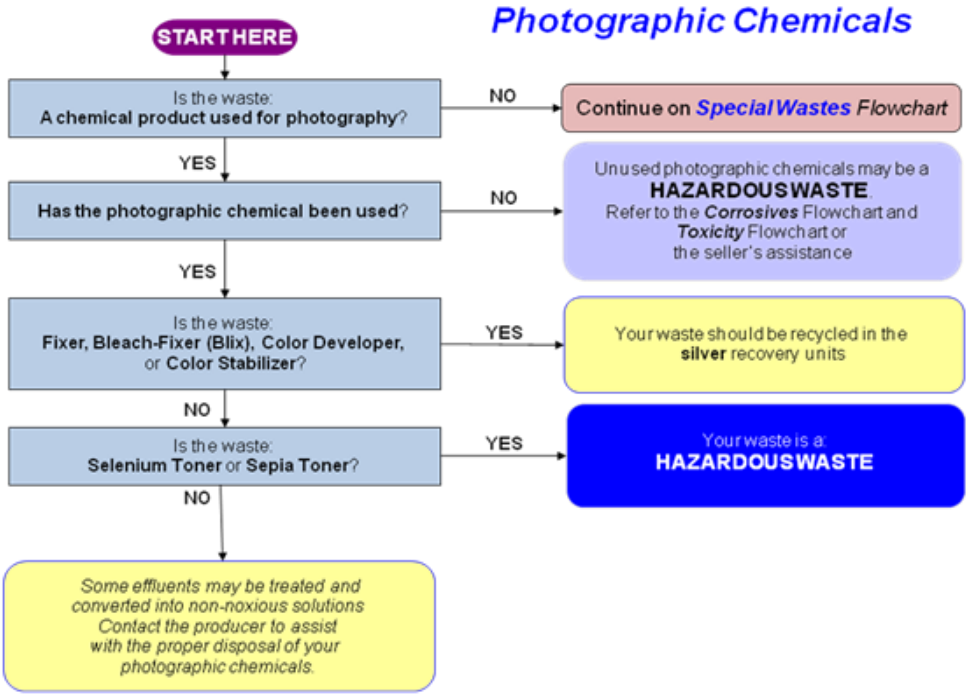

Paint Waste
START HERE
Is the waste:
Paint Related Waste?
(including Latex Paint, Oil Based Paint, Lacquer Based Paint, Paint Solvents and Thinners)
NO
Continue on Special Wastes Flowchart
YES
Type of Paint Related Waste
Latex Paint
Oil Based Paint
Lacquer Based Paint
Paint Solvents & Thinners
There are alternative disposal options for latex paint
air drying is acceptable with hardeners and bentonite litters
Your waste is a:
HAZARDOUS WASTE
Please note that general Air Quality Regulations do NOT allow us to dry out oil-based paints or solvents for the purpose of disposal.


Asbestos Waste
START HERE
Does the waste:
Contain > 1% Asbestos?
Examples of Materials commonly containing Asbestos (but not limited to):
• Sheet Rock Taping and Joint Compound
• Fire Door Core Material
• Roofing Felt
• Floor Tile and Mastic
• Cementious Panels
• Sprayed-on Ceiling Materials
• Boiler Insulation
• Pipe Insulation
• Brake Pads
• Clutch Pads
• Gaskets
• Electrical Wire Insulation
• Thermal Insulation on Electrical Appliances
YES
Your waste is a:
HAZARDOUS WASTE
needs proper disposal
NO
Continue on Special Wastes Flowchart

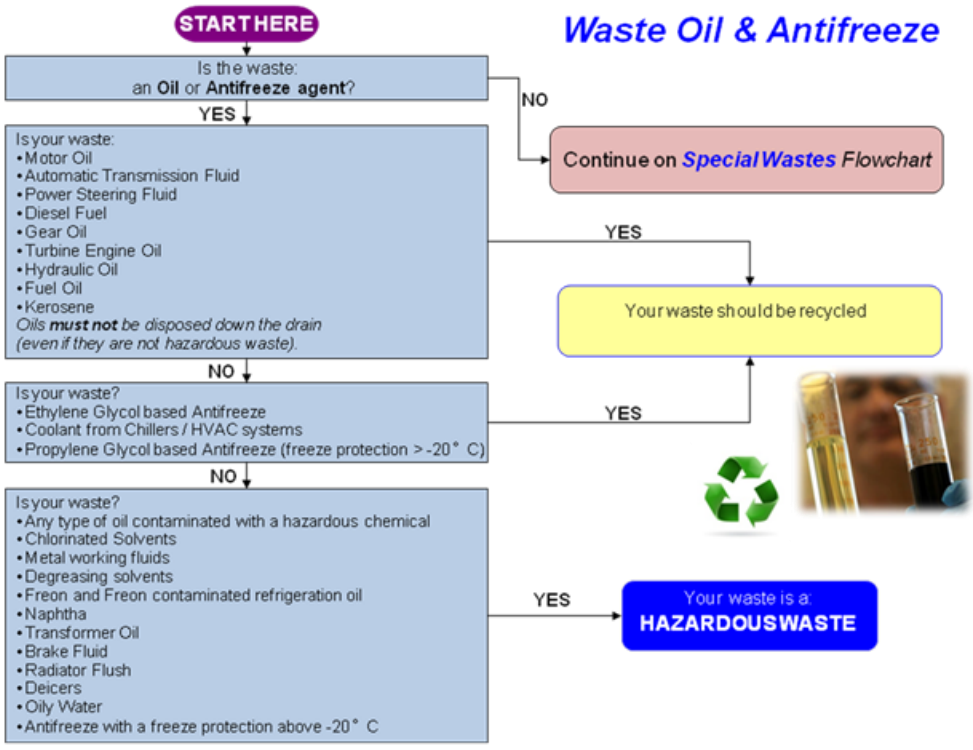

START HERE
Compressed Gas Cylinders & Aerosols
Is the waste an aerosol container?
YES
NO
Is the container: Completely emptied of the contents to the maximum extent practical under normal use (1 bar) (i.e., the spray mechanism is not defective)?
NO
Your waste is a: HAZARDOUS WASTE
YES
Did the container: formerly contain a Hazardous Waste?
YES Or don't Know
Your aerosol container even if completely empty is a: HAZARDOUS WASTE
NO
Dispose of in regular trash
Is the waste a: Compressed gas cylinder or a single use propane canister? (including gas cylinders, lecture bottles or refillable LPG canisters)
YES
Contact the Supplier or Manufacturer and arrange to have the compressed gas cylinder returned to them for proper disposal.
If not returned to the Supplier or Manufacturer, your waste is a: HAZARDOUS WASTE.
NO
Continue on Special Wastes Flowchart


START HERE
Empty Containers
Is the waste: An "empty" container that formerly contained a hazardous material?
NO
Continue on Special Wastes Flowchart
YES
Does the waste: meet the definition of EMPTY?
For containers that held a pourable hazardous material... No further material can be poured or drained from the container when it is held in any orientation.
For containers that held a non-pourable hazardous material... No hazardous material remains in the container that can be removed by physical methods.
NO
Your waste container, even if completely empty, is a: HAZARDOUS WASTE
YES
Did the empty container: Formerly contain a material that had an oral LD50 < 50 mg/kg? (refer to the Toxicity section on Material Safety Data Sheet)
YES
NO
Did the empty container: Formerly contain an Extremely Hazardous Waste?
YES or DON'T KNOW
NO
All containers must be triple rinsed before disposal.
If the container held a strong-smelling material, rinse with an appropriate solvent. If the cleaning solvent is a hazardous material, collect and dispose of as a hazardous waste.
Deface label and mark "triple rinsed".
Recycle glass, bottles and cans where possible.
Under no circumstances may a container labeled with the international radioactive symbol be disposed of in the regular trash.





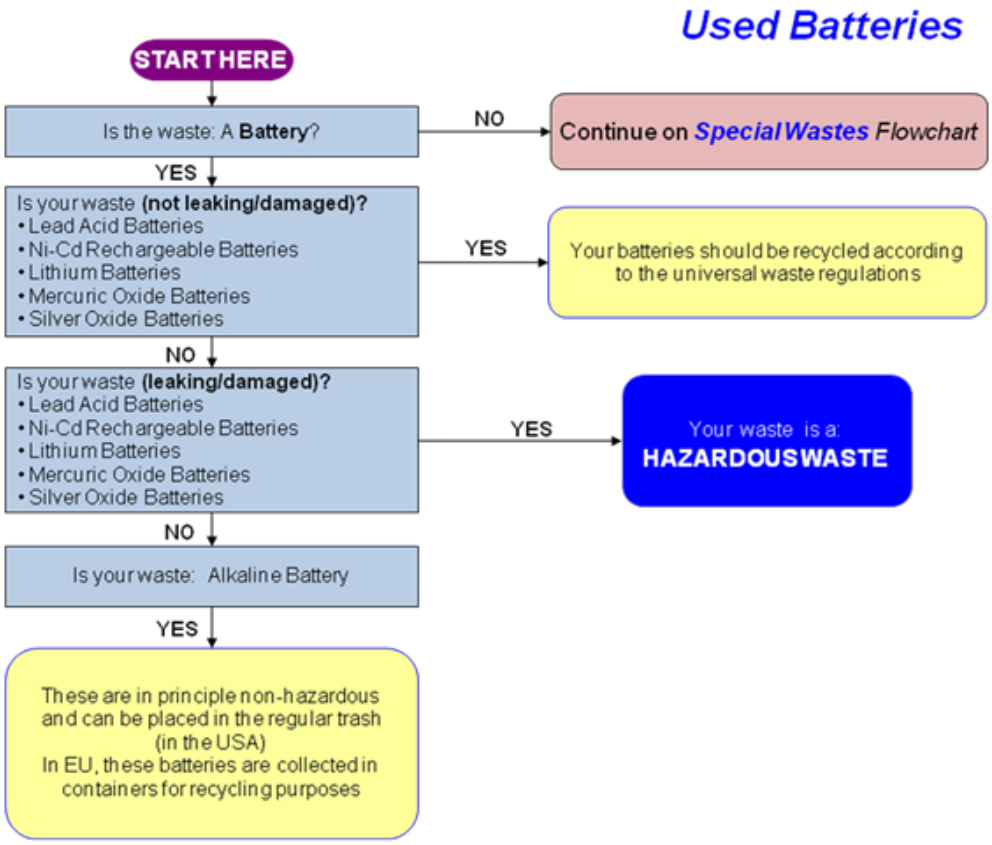
Actually, the impact of the production of silver-salt based photographic waste is gradually decreasing, thanks to the constant growth of digital imaging. However, the use of conventional photography is still relevant for some medical or sanitary applications, *e.g.*, dentistry or radiographic investigation in minor hospitals.



The case of **used mineral lubricant oil** is an example of efficient full recovery in most countries that is worth to be mentioned.
Spent lubricant oil is a **highly hazardous waste**. If spilled into water, 4 kg of oil can pollute a surface equivalent to a football ground. So, oil regeneration is the process that exploits at best the collected spent oil.
Regeneration transforms the used oil into a lubricant base, with qualitative physical-chemical characteristics similar to virgin oils directly derived from crude mineral oil.

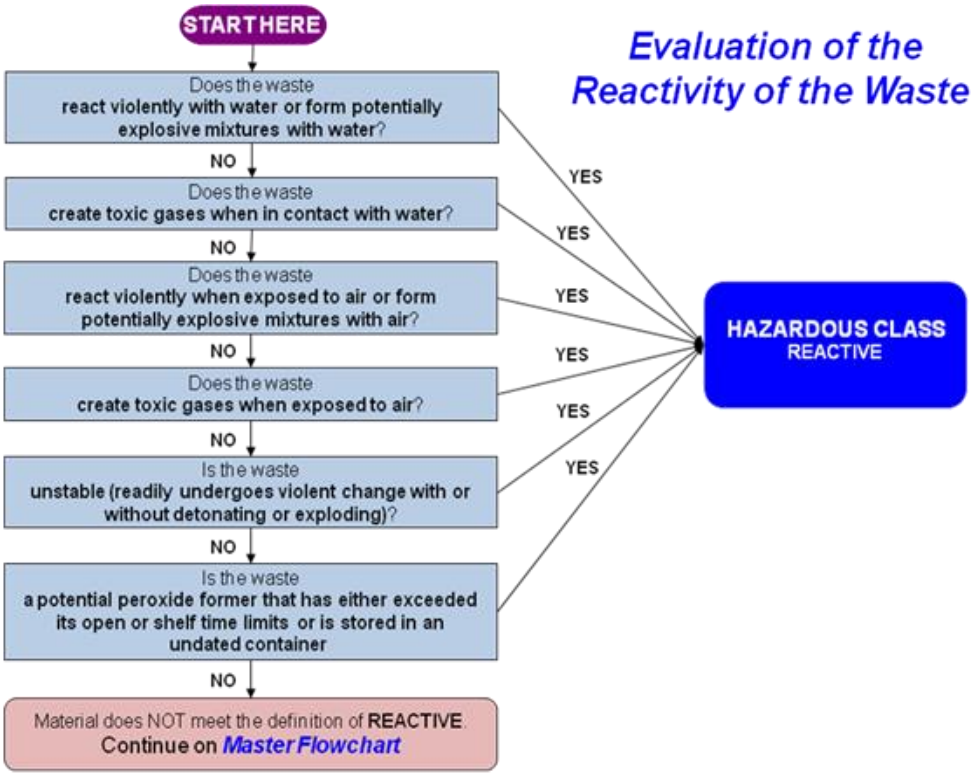
Regeneration shows a very high yield: starting **from 100 kg of waste oil**, **65 kg** of **lubricant** base oil and **20-25 kg of Diesel oil** and/or **bitumen** are obtained.
This means a remarkable saving on the global import/export balance of mineral oil derivatives in a country.
For instance, 25% of the Italian market of lubricants comes from regenerated waste oils.

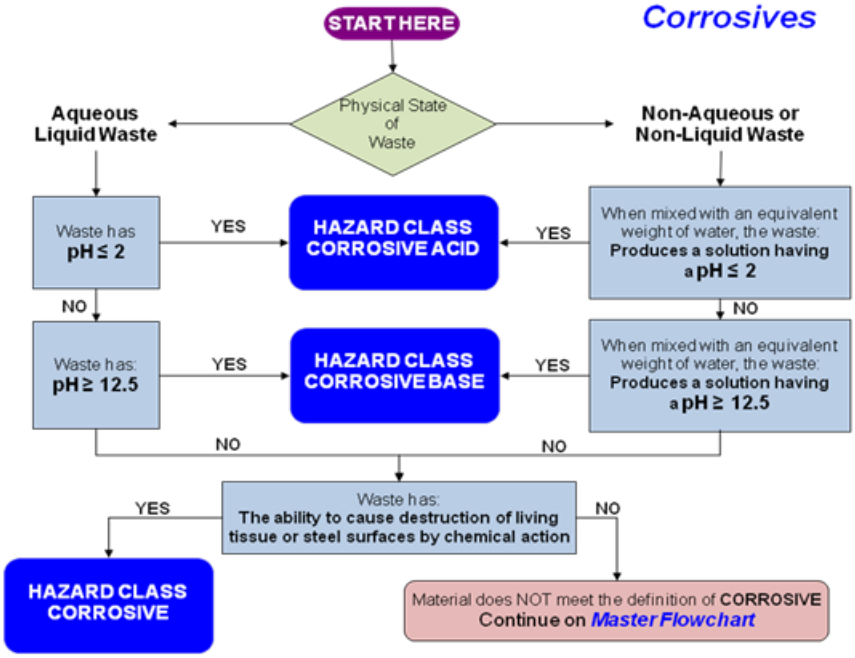
In Italy, in 29 years, 4.90 Mtons of waste lubricant oil were collected, of which 4.34 Mtons were recycled and sent back to market. This implies that only 0.5% of the total amount of the spent oil has been directed to the thermal destruction.

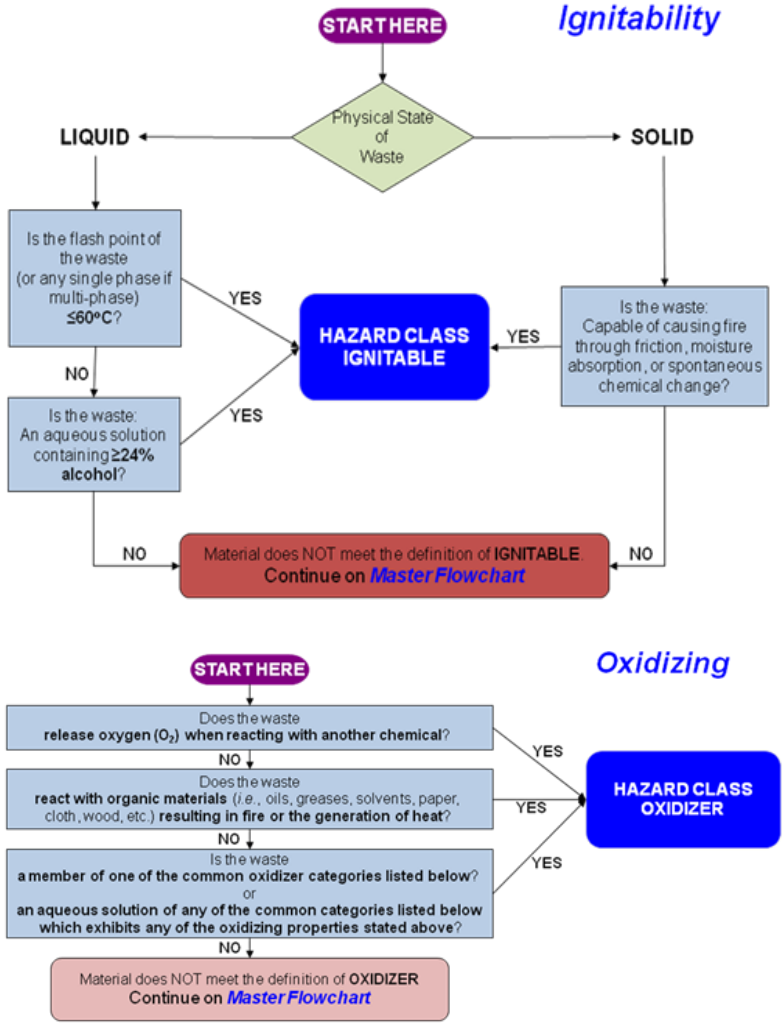


Especially in the analysis of waste streams originating from chemical laboratories and/or small manufacture units, where a wide range of compounds and products are used and generated, a careful evaluation of the reactive character and nature of the components of the waste is needed.

The following sub-flowchart helps in taking into consideration whether secondary undesired hazardous reaction may occur during the final treatment of the waste, especially when in contact with other waste materials.


START HERE
Evaluation of the Reactivity of the Waste
Does the waste react violently with water or form potentially explosive mixtures with water?
NO
Does the waste create toxic gases when in contact with water?
NO
Does the waste react violently when exposed to air or form potentially explosive mixtures with air?
NO
Does the waste create toxic gases when exposed to air?
NO
Is the waste unstable (readily undergoes violent change with or without detonating or exploding)?
NO
Is the waste a potential peroxide former that has either exceeded its open or shelf time limits or is stored in an undated container
NO
Material does NOT meet the definition of REACTIVE.
Continue on Master Flowchart
YES
YES
YES
YES
YES
YES
HAZARDOUS CLASS
REACTIVE

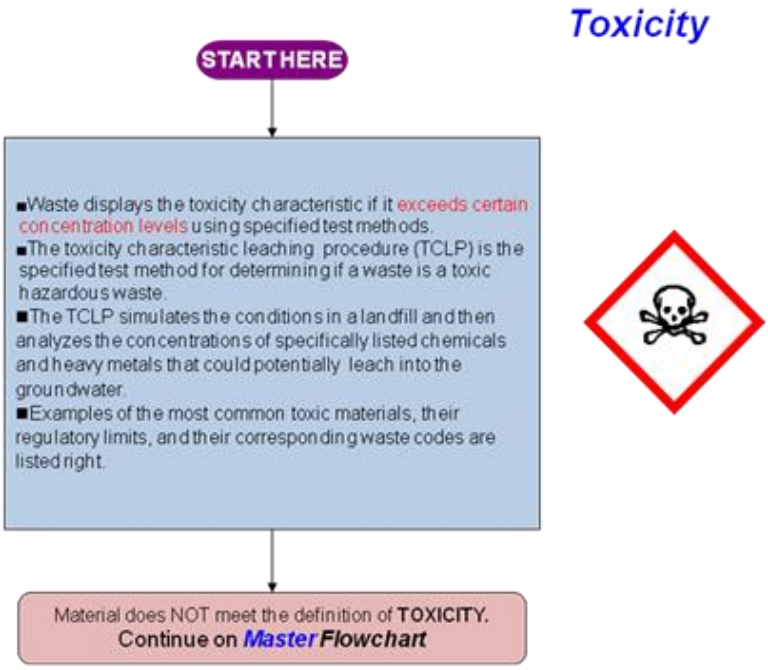

START HERE
Corrosives
Physical State of Waste
Aqueous Liquid Waste
Non-Aqueous or Non-Liquid Waste
Waste has pH ≤ 2
YES
HAZARD CLASS CORROSIVE ACID
YES
When mixed with an equivalent weight of water, the waste: Produces a solution having a pH ≤ 2
NO
NO
Waste has: pH ≥ 12.5
YES
HAZARD CLASS CORROSIVE BASE
YES
When mixed with an equivalent weight of water, the waste: Produces a solution having a pH ≥ 12.5
NO
NO
Waste has: The ability to cause destruction of living tissue or steel surfaces by chemical action
YES
NO
HAZARD CLASS CORROSIVE
Material does NOT meet the definition of CORROSIVE
Continue on Master Flowchart



In the class 'oxidising' one can find a broad series of chemicals typically used in chemical laboratories, some of them being particularly dangerous.

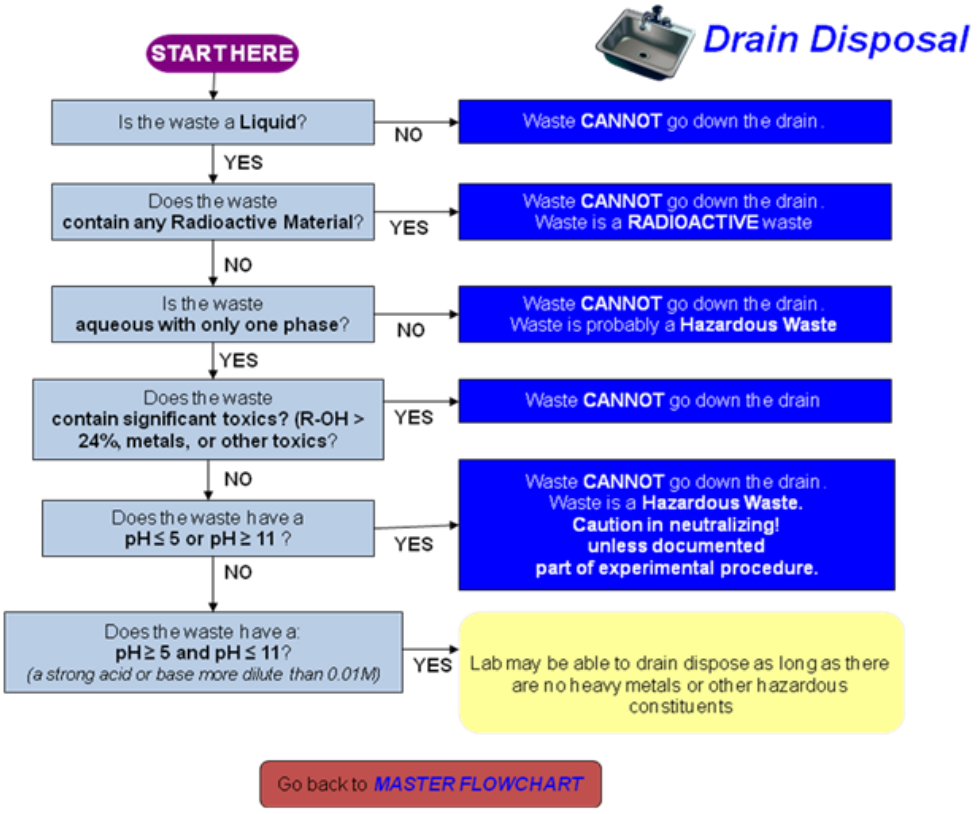
Solids: bismuthates, bromates, chlorates, chlorites, chromates, chromium trioxide, dichromates, ferric sulfate, ferric chloride, ferric trioxide, ferricyanides, hypochlorites, iodates, iodine, manganese dioxide, nitrates, perborates, perchlorates, periodic acid, permanganates, permanganic acid, peroxides or persulfates.

Liquids: bromine, chromic acid (pH > 2, in fact, oxidizing mixtures having a pH < 2 are classified as corrosive), hydrogen peroxide, nitric acid (pH > 2), perchloric acid (pH > 2), sulfuric acid (pH > 2).



Finally, the last sub-flowchart is particularly important, since the definition of a material as a '**non-waste**' allows one to dispose it of in the ordinary urban sewage system, without overloading the waste stream of the laboratory and thus with a remarkable reduction of some handling and post-treatment problems.
It is necessary, however, a strict assessment of the characteristics and nature of the waste. In the case of any minor doubt about the real nature of the material, it is indeed compulsory to treat and handle the waste as a hazardous one.

In addition, in the evaluation of the pH value of the waste material that is potentially disposed of in the drain, the range shown in the flowchart (*i.e.*, 5 < pH < 11) may vary according the local requirements and rules of the urban sewage systems. Some companies may accept more alkaline effluents, according to the average pH of the urban sewage stream and to the robustness of the biological post-treatment for the liquid streams.



In conclusion, the present flowchart can be used as a first rule-of-thumb for the rapid classification of a new or unknown waste stream. However, a detailed case by case analysis must be always performed when a constant and non-negligible production of waste of the same nature is expected.

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6 Current Trends and Future Scenarios

6.1. Sustainable Development and Green Chemistry

The following section gives some hints about the current trend, at global level, for a more sustainable and environmentally friendly way of 'making Chemistry'. In fact, one of the main goals of the production and manufacture of chemicals, both at industrial and laboratory level, for the 21st Century is the minimization or, at least, the reduction of undesired by-products and waste materials.

A milestone in the definition of **Sustainable Development** is the one given by the World Commission on Environment and Development, in the report: Our Common Future, in 1987:
"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

In addition, the **Guidelines** of the UN Commission on **Sustainable Development** indicate that it is necessary to:

- Avoid to alter systematically the natural distribution of resources in Earth's crust (*e.g.*, noble metals, rare earths elements, phosphorus, critical raw materials);
- Avoid to increase systematically the amount of persistent compounds from human origin (*e.g.* CO_2, chlorofluorocarbon, CFC, dichlorodiphenyltrichloroethane, DDT);
- Avoid to modify systematically the physical/chemical rules of the Earth's natural productive cycles;
- Go towards the careful and efficient use of the natural resources, in accordance with mankind's needs.

In summary, Sustainable Development means a fine balance among the following primary needs:

1. **Societal needs** (social target)
2. Efficient use of **residual resources** (economic target)
3. Need to **reduce Mankind's footprint** on the Environment, so to assure the natural basis for Life (environmental target)

In this context, a **resource** is a raw material obtained from the (living or non-living) environment to satisfy human needs. Such resources can be exploited to obtain **Energy**, **Products**, **Food** and **Feed**.

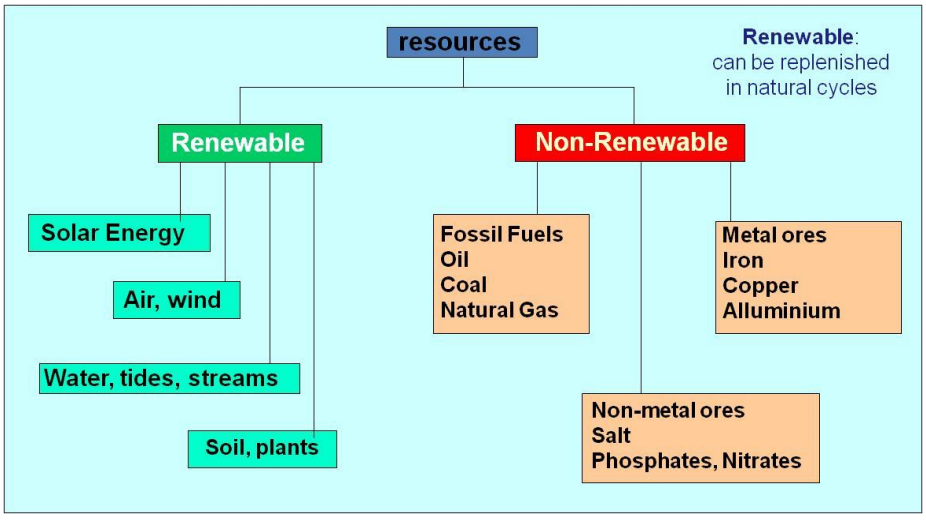


Figure 6.1 Classification of Resources

In the quest for a sustainable development, Chemistry, as a Science, plays a pivotal role. Therefore, the so-called **Green Chemistry** or **Sustainable Chemistry** (as it is called preferentially in some countries) collects all those *"technologies that are energy efficient, minimize or preferably eliminate the formation of waste, avoid the use of toxic and/or hazardous solvents and reagents and, where possible, utilize renewable raw materials"*.

Green Chemistry is about:

- **Waste Minimisation** at Source
- Use of **Catalysts** in place of Reagents
- Using **Non-Toxic Reagents**
- Use of **Renewable Resources**
- Improved **Atom Efficiency**
- Use of **Solvent Free** or Recyclable Environmentally Benign Solvent systems

As it is evident from the above-mentioned statements, the reduction of waste materials and the elimination of hazardous chemicals (as a reagent or as final product) is a major objective. This may give rise to an easier and safer waste handling and management and for these reasons, the Green Chemistry guidelines are a valuable approach for the present study on all the steps of waste generation and supervision.

Green Chemistry is, actually, about **reducing waste**, **materials**, **hazards**, **risks**, **energy and costs**. It is worth highlighting that an **environmental** sustainability must not be independent of an **economical sustainability**.

Such concepts are summarized in the:

12 Principles of Green Chemistry

1. **Prevention:** It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom Economy:** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. **Less Hazardous Chemical Synthesis:** Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to people or the environment.
4. **Designing Safer Chemicals:** Chemical products should be designed to effect their desired function while minimizing their toxicity.
5. **Safer Solvents and Auxiliaries:** The use of auxiliary substances (*e.g.*, solvents or separation agents) should be made unnecessary whenever possible and innocuous when used.
6. **Design for Energy Efficiency:** Energy requirements of chemical processes should be recognised for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. **Use of Renewable Feedstock:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce Derivatives:** Unnecessary derivatization (use of blocking groups, protection/de-protection, and temporary modification of physical/chemical processes) should be minimised or avoided if possible, because such steps require additional reagents and can generate waste.
9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation:** Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. **Real-time Analysis for Pollution Prevention:** Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently Safer Chemistry for Accident Prevention:** Substances and the form of a substance used in a chemical process should be chosen to minimise the potential for chemical accidents, including releases, explosions, and fires.

Taking into account these principles and adopting a more sustainable way of 'making Chemistry', it is possible to reach higher levels of the Pollution Prevention Hierarchy:

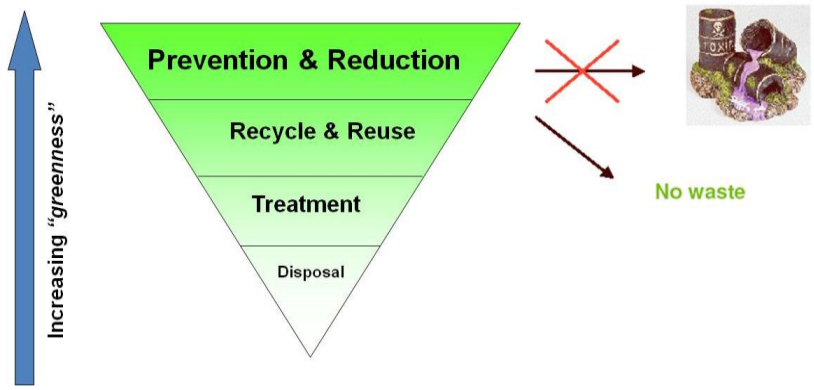


Figure 6.2 A scheme for the Pollution Prevention Hierarchy

The design of new syntheses of chemical compounds is a field in which the guidelines of Green Chemistry can be applied at their best.

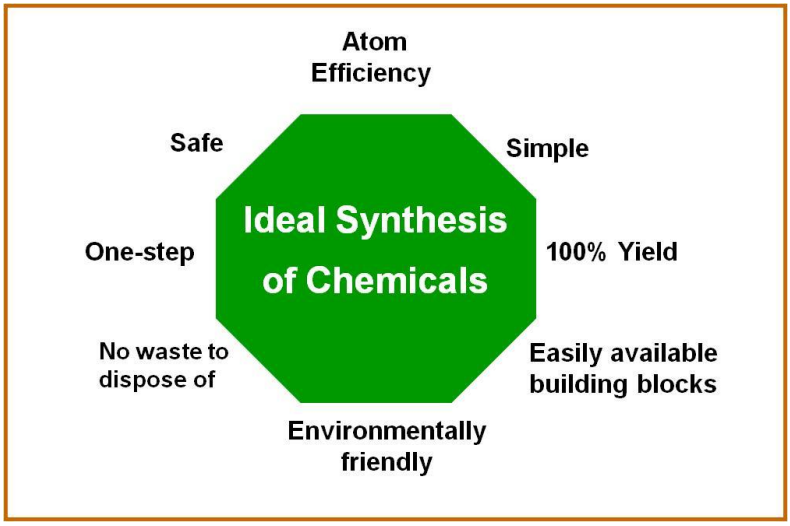


Figure 6.3 An 'ideal' chemical synthesis

6.2. Green metrics and case studies

It is often useful to ask: **Where does the waste come from?** and **How is it possible to quantify the waste?**
In this scenario, it is interesting to pay attention to the relationships between **Chemical Industry** and **Production of Waste**. It is, indeed, necessary to shed some light onto widely-accepted commonplaces about the polluting capability of various types of chemical industry.

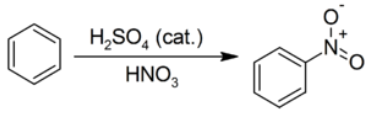
Industry Segment	Tonnage (tons)	RATIO mass by-products / mass product
Oil Refining	10^6 - 10^8	<0.1
Bulk Chemicals	10^4 - 10^6	1 - 5
Fine Chemicals	10^2 - 10^4	5 - 50
Pharmaceuticals	10 - 10^3	25 - 100+

Chemical productions traditionally considered as “dirty”, such as oil refinery and bulk petrochemistry, are relatively “clean”. On the other hand, highly specialized industries, with more relevant added values and making use of a complex Chemistry, produce a far larger amount of waste materials.

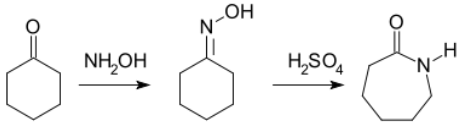
Some classical examples are:

I. Stoichiometric Brønsted Acids and Bases

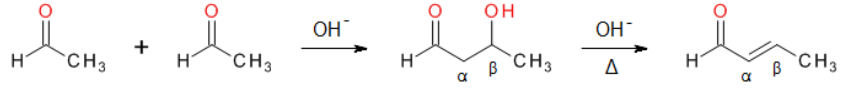
- Nitration of aromatics with H_2SO_4/HNO_3



- Acid-catalyzed rearrangements, e.g. Beckmann (H_2SO_4)

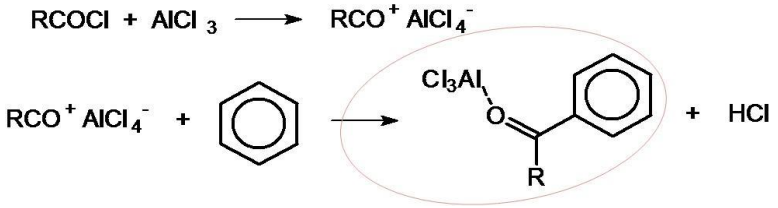


- Base-catalyzed condensations, e.g. aldol (NaOH, NaOMe)



II. Stoichiometric Lewis Acids

- Friedel-Crafts acylations ($AlCl_3$, $ZnCl_2$, BF_3)

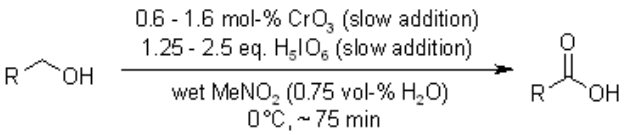


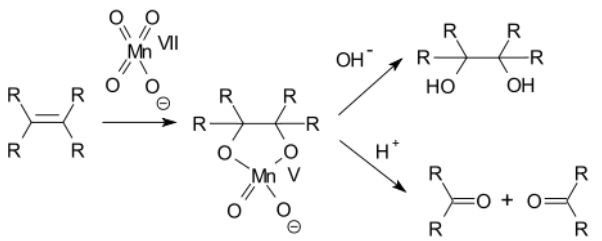
since in the conventional process the acid is NOT catalytic and an over-stoichiometric amount of the Lewis acid is needed to allow the formation of the 1:1 adduct with the final acylated product.

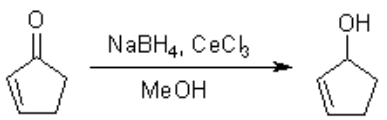
III. Stoichiometric Oxidants and Reductants

- $Na_2Cr_2O_7$, $KMnO_4$, MnO_2

- $LiAlH_4$, $NaBH_4$, Zn, Fe/HCl

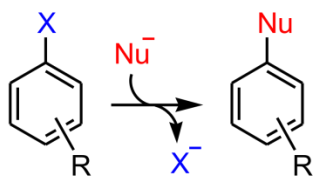




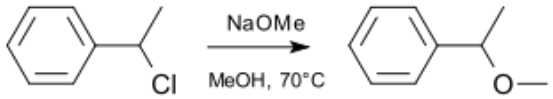


IV. Halogen Addition and Halogen Substitution

- Nucleophilic Substitution



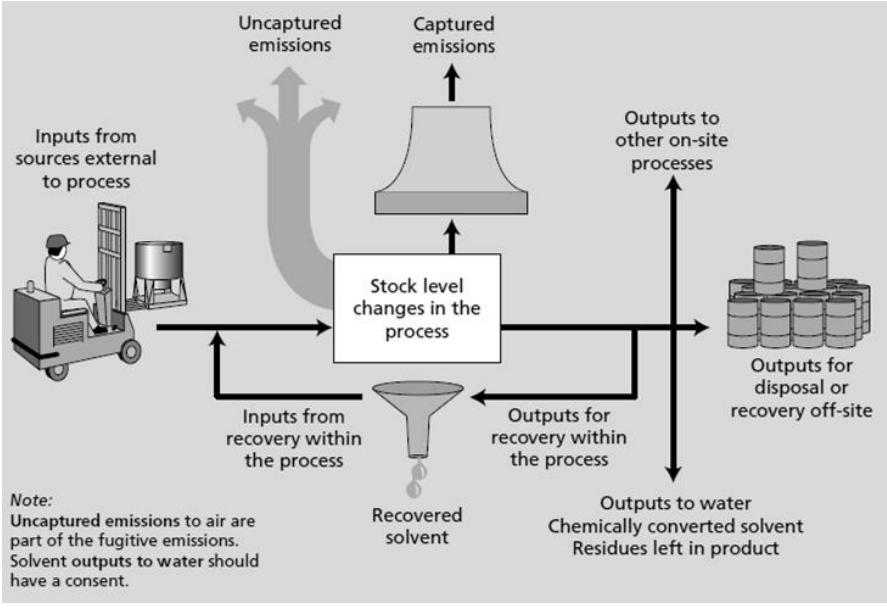
X = halogen etc. Nu = nucleophile



rate = k_1 [PhCHClCH$_3$] + k_2 [PhCHClCH$_3$][NaOMe]

V. Solvent Losses

- Emissions in air, aqueous effluents and cooling fluids



In the 1990s a set of **fundamental parameters** were defined, in the field of Green Chemistry, in order to **quantify the degree of environmental friendliness** of a **chemical reaction**, **transformation** or **industrial process**. The series of such parameters is also called **Green-Metrics**.

6.2.1 Green metrics parameters

E-Factor (environmental factor).

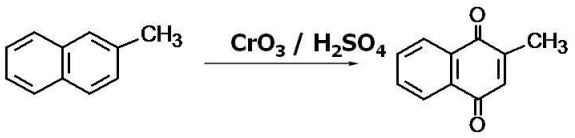
E-factor = [total waste (kg)] / [product (kg)]

This parameter depends on what we define waste. It includes: every chemical used in the process as well as the compounds needed for abatement/after-

treatment/work-out, even though some by-products (or side products) may find use and market as secondary products.
The E-factor is a practical parameter, very useful for industry and teaching. It can be split in sub-categories: Organic waste; Aqueous waste; etc.
The smaller the number, the closer we are to zero waste option.
At industrial level can be computed from the values of amount of raw-materials bought and the amount of products sold:

E-factor= [(chemicals in) – (products out)]/[(products out)]

e.g.



E factor = 18

18 kg of waste per 1 kg of product

Industrial production of vitamin K_3

1500 tons/year

Top. Curr. Chem. 164 (1993) 21

Yield and Selectivity

These values are not exclusive parameters of Green Chemistry.

- **Yield of a reaction**

$$\text{Y \%} = \frac{\text{real amount of obtained products}}{\text{theoretical amount of obtainable products}} \times 100$$

- **Selectivity of a reaction**

$$\text{S \%} = \frac{\text{yield of desired product}}{\text{amount of converted reactant}} \times 100$$

Atom Economy

$$\mathbf{A + B \longrightarrow C + co\text{-}products}$$

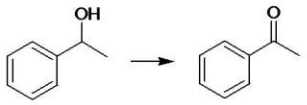
$$\text{Atom Economy (AE)} = \frac{\text{MW C}}{\text{MW A + MW B}}$$

MW
molecular weight

The **Atom Economy** is an evaluation of "how many atoms of the reactant" are found in the final product. It is a theoretical value, not experimental and does

not take into account solvents, reaction yield, molar excess of reactants, reactants of final "work-up".
The larger the number, the bigger is the percentage of atoms from the reactants in the product(s). It is, by definition, a value between 0 and 1. **0 < AE < 1**

example : **oxidations**
stoichiometric *vs* catalytic



Stoichiometric: **Jones reagent**

$3PhCH(OH)CH_3 + 2CrO_3 + 3H_2SO_4 \rightarrow 3PhCOCH_3 + Cr_2(SO_4)_3 + 6H_2O$

AE = 360 / 860 = **42%**
E_{theor} = ca. **1.5**

Catalytic: homogeneous or heterogeneous Co, Mn or Ag

$PhCH(OH)CH_3 + 1/2O_2 \rightarrow PhCOCH_3 + H_2O$

AE = 120/138 = **87%**
By-product: H_2O
E_{theor} = ca. **0.1(0)**

Atom Efficiency

$$Atom\ Efficiency = \%Yield \times Atom\ Economy$$

The Atom Efficiency is a peculiar parameter as it mixes the practical character of Yield with the theoretical one of Atom Economy.
e.g.: atom economy can be 100%, but the yield 5% only, so the global process cannot be fully sustainable!
The closer this parameter is to 100%, the "greener" is the process. **0% – 100%**

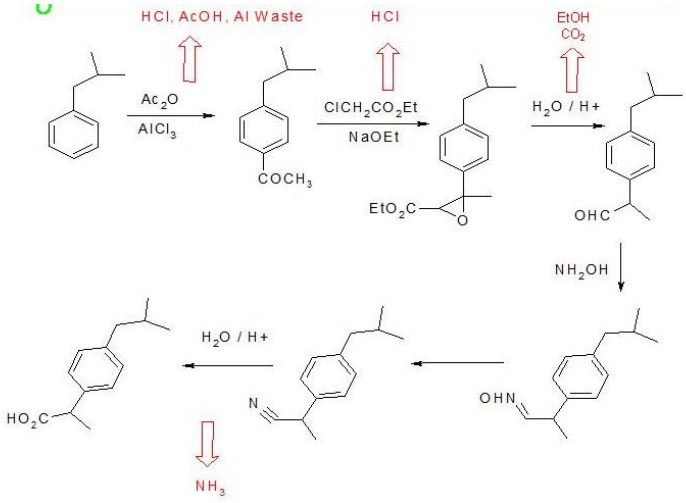
A series of exemplar cases of industrial chemical transformations (mainly taken from the fine chemicals industry, whose environmental is often higher) is here reported and the green-metrics of these processes is analysed.

6.2.2 Exemplar case studies

A selection of exemplar cases of industrial application of the Green chemistry principles are hereafter reported.

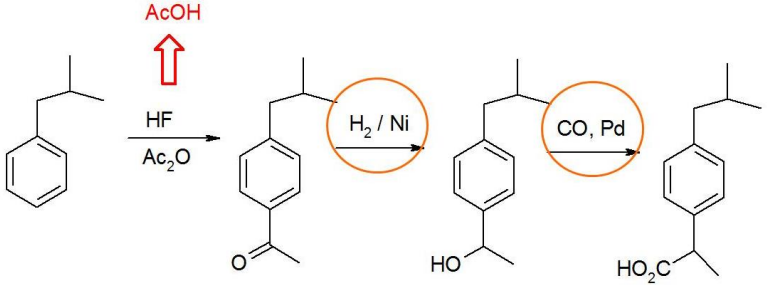
Industrial large-scale synthesis of Ibuprofen

Classic Route to Ibuprofen



The conventional, widely-accepted route is based on a **3-step synthesis** with an Atom Economy of **77%**. If the acetic acid in step 1 is isolated and recycled, the Atom Economy may rise to 99%. The most relevant waste is due to solvents, $AlCl_3$ and its salt derivatives.

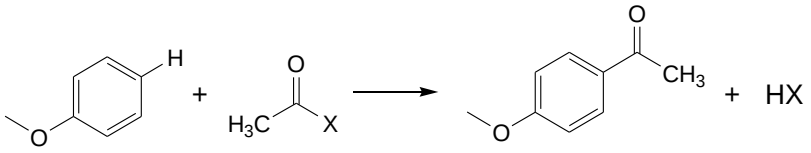
Alternative Route to Ibuprofen



The **alternative route**, proposed and set up by Boots-Hoechst-Celanese (now BASF Corporation), replaces $AlCl_3$ with HF and avoids the use (and the co-production) of chlorine-containing waste products. In addition, the reduction and carbonylation steps are carried out over heterogeneous recyclable catalysts and, in each step, the Atom Economy is total (100%). This alternative route was awarded with the Presidential Green Chemistry Challenge: 1997 Greener Synthetic Pathways Award, of the United States EPA.

Acetylation of Anisole

Friedel-Crafts reaction and Fries rearrangement are two of the most important methods for the preparation of aromatic ketones in Fine Chemical Industry.



C. Friedel, J. M. Crafts, Bull. Soc. Chim. Fr., 27 (1877) 482

The conventional method relies on the use of stoichiometric amounts of Lewis acid salts ($AlCl_3$, $ZnCl_2$ or $FeCl_3$, typically) with the co-production of huge amounts of hazardous salt waste. The new process, based on acetylation over acid solid zeolites, leads to the substitution of the previous technology based on:

$AlCl_3$ catalyst, AcOCl acylating agent and batch reactor with a new one:

zeolite catalyst (protonic Beta, H-BEA or protonic Faujasite, H-FAU), AcOAc acylating agent, fixed-bed reactor.

This change means: simpler process, higher selectivity to desired *para*-substituted products, relevant reduction of liquid effluents and, overall, an economic advantage.

From an industrial point of view, the new process involves **two steps instead of eight**.

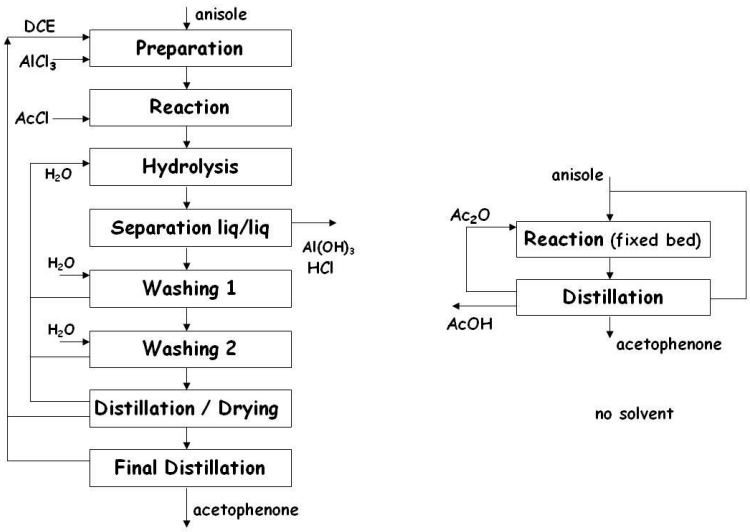


Figure 6.4 Comparison between the conventional stoichiometric acetylation process (left) and the innovative zeolite-based one (right)

This means also a large diminution in by-products:

- Huge reduction in aqueous effluents
- 35 kg / ton instead of 4.5 ton / ton of acetophenone (product)
- Reduction of organic by-products (2 -3 times less)
- No more inorganic by-products
- no more 5 wt.% of Al^{3+} and 24 wt.% of Cl^-

and in costs:

- Continuous process on fixed bed instead of a batch-wise process.

A sustainable process for the synthesis of Sildenafil

The production of a high-added value pharmaceutical compound such as Sildenafil, also known as Viagra™, was, at the beginning, in the 1990s, a largely polluting process.

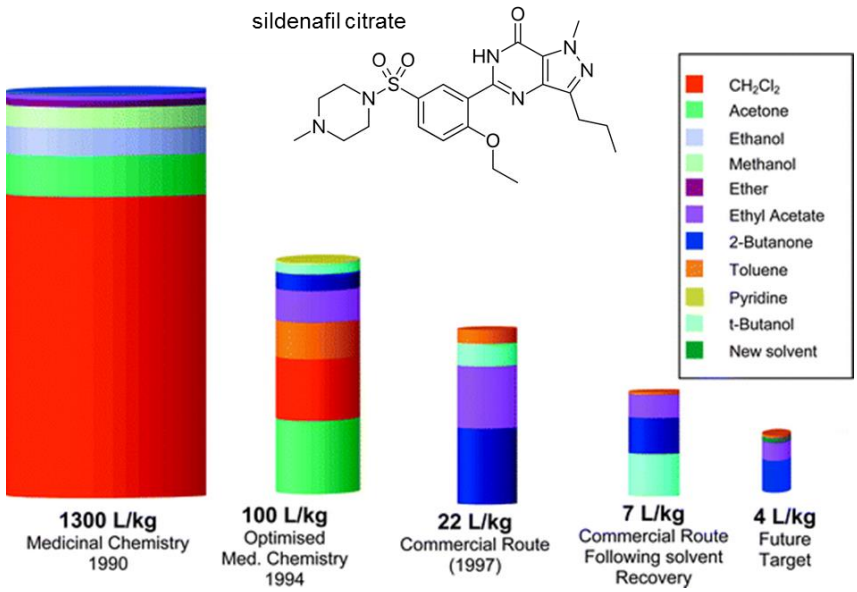
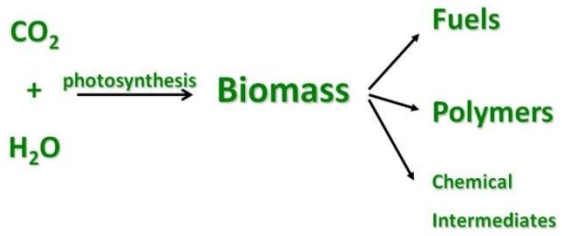


Figure 6.5 The amount of organic waste produced per kilogram of sildenafil citrate in the synthesis processes in various periods
(from P. J. Dunn, S. Galvin, K. Hettenbach, Green Chem., 6 (2004) 43)

The optimization of the synthetic strategies and of the reaction used allowed the company to reduce dramatically the amount of side-products produced down to values comparable to the ones of intermediate chemical industry. Indeed, thanks to its E-factor of ca. 5-6, the synthesis of sildenafil citrate is comparable to the manufacture of a bulk chemical commodity.

Biorefinery Concept

The concept of **biorefinery**, that is currently a leading idea in European Countries as a novel approach to chemical industry, grows from the seminal principles of Green Chemistry and is based on the complete and versatile exploitation of **renewable raw materials** and **biomass**.



Using biomass as a starting compound, the raw material is, generally, more easily biodegradable; CO_2 neutral; it involves less emissions of polluting agents and may mean added profits for agriculture and farmers (even though there are controversial points of view on this topic).

The type of biomasses the international scientific community is paying attention to are:

Organic waste and side-products from wood and pulp industry

- Grass and organic waste from farms
- Vegetable products grown for chemistry and energy
- Waste from food industry
- Urban and industrial waste
- Urban sludges
- Waste from sea-farming.

However, several problems and drawbacks may occur:

- Resources can be available at different levels year by year according to the variety of crops (and location);
- the use of Genetic Engineering can be a problem in several countries;
- An intensive farming leads to land depletion and induces desertification;
- Food/Feed competition.

From the mere chemical point of view, biomass materials are complex mixtures, difficult to be isolated and with high process costs, since they are richer in oxygenated compounds than fossil raw materials.

The biorefinery concept is based on **platform molecules**, which play a key role similar to the main fractions of petrochemistry. Platform molecules are bio-derived intermediates of pivotal importance linking the basic transformation of

biomasses with the traditional chemical industry, leading to the manufacture and synthesis of a very broad series of intermediates and derivatives for every-day use, that are already available as commodities, from oil-based sources.
Five platform molecules out of ca. 30 have been evidenced by the United States Department of Energy on which research is fully active at global scale. They can be easily obtained from glucose:

Lactic acid; Succinic Acid; 3-Hydroxypropionic Acid; Itaconic Acid; Glutamic Acid

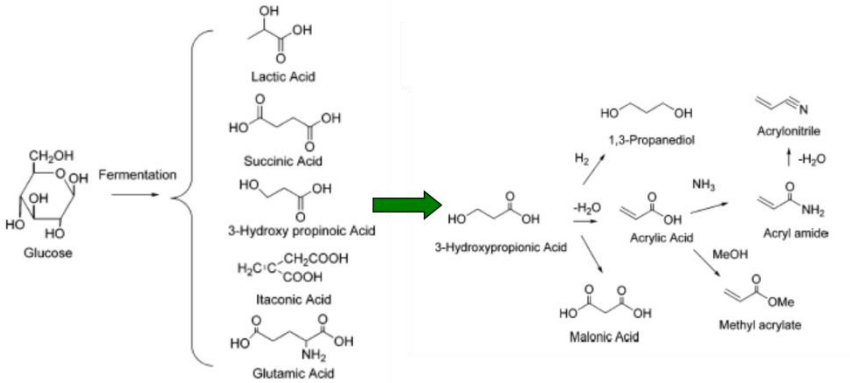
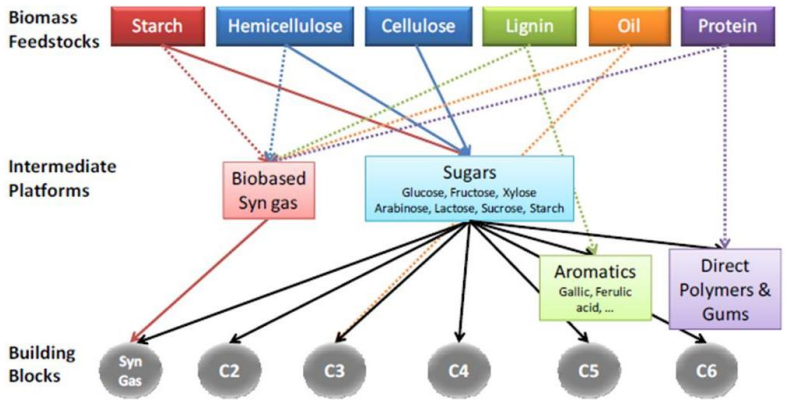
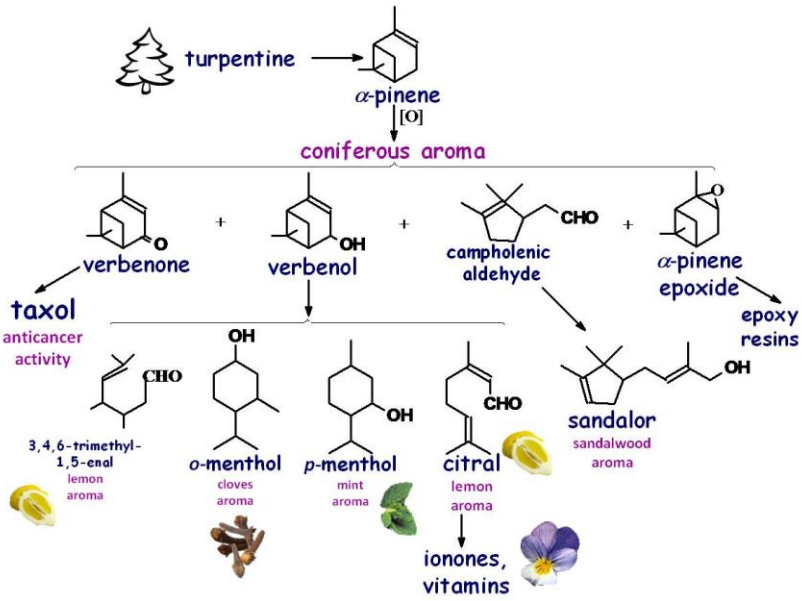


Figure 6.6 Potential pathways for converting one platform molecule, i.e. 3-hydroxypropionic acid, into industrially valuable chemicals



Analogously a very wide variety of high-added value chemicals for the **flavours and fragrances industry** can be obtained and produced from waste of the wood and pulp industry, by simple redox transformation of largely occurring **terpenes** found as secondary metabolites of coniferous plants and vegetables.



In summary, **Green Chemistry** or **Sustainable Chemistry** is not a new branch of Chemistry, rather it is 'the Chemistry' of XXI century.

Every Chemist's work should be guided by these **Green Criteria** and a thorough **evaluation of the sustainability** of a **chemical process** should always be performed prior to the scale-up of a novel synthesis route from laboratory-scale to industrial level.

A careful application of these guide-lines leads to a **remarkable reduction** of **waste materials, risks, hazards, materials** and **costs**.

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