EUROPEAN FEDERATION OF CLINICAL CHEMISTRY
AND LABORATORY MEDICINE

Green Labs

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EFLM GUIDELINES FOR GREEN AND SUSTAINABLE MEDICAL LABORATORIES

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PRODUCED BY THE EFLM TASK-FORCE GREEN LABS

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EFLM set up a “TASK-FORCE GREEN LABS” to help medical laboratories to implement sustainable practices and improve their sustainability performance across Europe and beyond.

It aims at gathering and sharing best practices to guide laboratories on their transition towards more sustainable spaces by decreasing their deleterious environmental impact and implementing efficient actions in laboratories, and taking steps to minimize energy, water, and hazardous chemical use, as well as waste generation without compromising the quality of healthcare.

1.1. BACKGROUND AND OVERVIEW

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Sustainability is the balance between the environment, equity, and economy (1)

A quoted definition from the UN World Commission on Environment and Development: states “sustainable development is development that meets the

needs of the present without compromising the ability of future generations to meet their own needs".

The 2015 United Nations Sustainable Development Goals are 17 global goals taking part in the United Nation's Sustainable Development Agenda to end poverty, to protect the planet and to ensure prosperity for all (2).

Each goal has specific targets to be achieved over the next 15 years. It is on the back of these goals that sustainable practices and the European Green Deal (EGD) have their foundation. The European Green Deal (EGD) aims at making Europe the world's first climate-neutral continent by 2050 and is an integral part of the European Commission's strategy to implement the United Nation's 2030 Agenda and the sustainable development goals (3).

It constitutes a great challenge for hospitals, health practitioners and the laboratory medicine community which use more energy and water than offices and generate huge amounts of hazardous and non-hazardous wastes. At the same time, it is a great opportunity to contribute to improving the sustainability performance of laboratories and healthcare systems across Europe.

The European Commission has already taken initiatives focusing on hospitals and healthcare stakeholders from which inspiration can be taken. An example of such a project is the RES-HOSPITALS project entitled "Towards zero carbon hospitals with renewable energy systems", which aimed at reducing CO_2 emissions from the existing stock of some 15,000 hospitals in Europe (3).

Laboratory medicine should contribute to a sustainable healthcare system ensuring that resources are used efficiently from ecological, social, and economical perspectives, while providing high-quality services to patients and physicians (Figure 1). Laboratory tests are already key elements for human health by helping physicians in the clinical decision process and by providing value for primary and secondary prevention (4,5). Clinical laboratories have also several opportunities to go forward in achieving sustainable operations to reduce their negative impacts on the environment and economy. Clinical laboratories use more energy and water than offices, generate huge amounts of hazardous and non-hazardous wastes. Labs are large consumers of energy and thereby contribute to the largest percentage of carbon emissions. Due to their relatively high energy requirements, hospitals and laboratories must strive to achieve the long-term CO_2-reduction targets set by the European Commission. Incorporating sustainable practices into daily lab routine will go towards saving energy, reducing emissions, and helping the European Green Deal (EGD) to reach its Climate and Sustainability Action Plan.

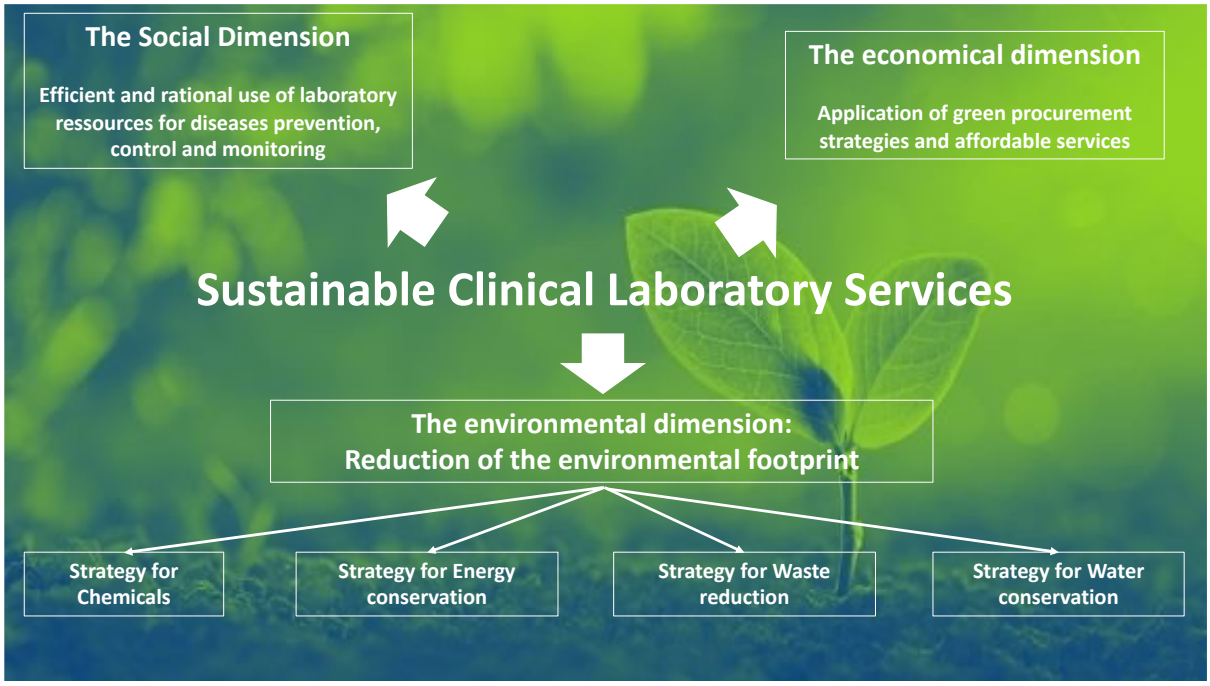

Figure 1: Clinical laboratories as contributors for the different dimensions of sustainability

Clinical laboratories can limit their environmental impact and provide sustainable laboratory services making reductions in four key areas-energy consumption, water consumption, waste production, and use of hazardous chemicals. Establishing sustainable development goals and applying multiple means for reductions in these key areas, hospitals and clinical laboratories can reduce their environmental impact. Sustainability measures should be a key feature in the rapidly changing healthcare environment. They are needed to reduce their negative impacts on the environment and economy. In order to provide high-quality, effective, and safe healthcare services, sustainable healthcare systems need to overcome major economic and social challenges. Though there will be initial capital costs, there is a long-term cost-saving potential of a more efficient use of energy and other resources in healthcare systems. Despite this, there is a long way to go for environment-friendly hospitals, healthcare structures, and clinical laboratories to become the norm.

1.2. EFLM TASK FORCE-GREEN LABS

The EFLM Executive Board approved the establishment of the Task Force-Green Labs proposed by the EFLM President-elect Tomris Ozben on November 17, 2021, and decided that the EFLM should lead the way in implementing sustainable clinical laboratory practices in Europe. The EFLM Task Force “Green Labs” was set up with that purpose. EFLM will steer the laboratory medicine community’s transition towards carbon neutrality in line with the European Green Deal (EGD).

The initial focus of this new Task Force is to develop guidelines, criteria, and key recommendations for mainstreaming sustainable practices in clinical laboratories (Green Lab Guide). Clinical laboratories can work to improve their sustainability performance by following the EFLM TF-Green Labs Guidelines, a set of recommendations and good practices in four major areas of their activity: energy, water, waste, and use of hazardous chemicals.

The EFLM Task Force-Green Labs will put in place a system that can guide, support, monitor European Laboratories' efforts to become Green Labs, and delivers EFLM Green Lab Certificate to the laboratories fulfilling the required criteria after assessing their status.

2. INTRODUCTION

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All human activity impacts the environment. Environmental factors contribute to climate change and consequently are the root cause of a significant burden of morbidity and mortality, particularly in developing countries. The resulting impact is estimated to cause about 25% of death and disease globally, reaching nearly 35% in regions such as sub-Saharan Africa (6). We can also mention that the environment through pollution is a recognized risk factor of morbidity and mortality (7,8). All organizations, including laboratories, have a societal obligation to do their part to alleviate the harm they do to the environment and to reduce the environmental consequences of their activities (6). Laboratories impact the environment in several ways, and they have a responsibility to reduce the environmental consequences of their activities (9).

The consequences include global warming because of energy usage, the resulting rise of seas levels, and changes in the ecology and disease patterns. They also involve, *inter alia*, the loss of irreplaceable resources, a reduction of biodiversity, atmospheric pollution, consumption of energy and water, production of heat, the ever-increasing production of waste and resultant contamination of sites by runoff or landfill. The changes of the various parameters that contribute to and which indicate global warming have been summarized by the National Aeronautical and Space Administration (NASA) of the United States.

Healthcare practices have a significant impact on the environment. Hospitals operate around the clock, every day and have large environmental footprints. They impact the environment in several ways (10). Besides energy, laboratories are also significant consumers of water and producers of waste and users of chemicals. It has been estimated that most of the existing laboratories can reduce their energy consumption by 30 to 50% using existing technology, which is significant given their $1 to 2 billion annual energy costs in the USA (11). Yet, few clinical laboratories have plans in place to address this situation, though most would like guidance if it were available (9). If unconscious consumption and waste production can be significantly reduced, it can lead to real cost

savings as well as an improved environmental footprint. Sustainable laboratories can be economically beneficial. Ross et al. (12) have described how they were able to generate over eight hundred thousand Australian dollars in savings through their implementation of ISO14001.

It is important that manufacturers, regulatory agencies, professional bodies, and their host institutions support laboratories in their efforts to improve their sustainability performance. For instance, in the UK, the UK health service procurement agency asks for net zero suppliers and the UK Sustainable Healthcare Coalition (https://sustainablehealthcare.org.uk/) verifies targets for net zero. In addition to the European Green Deal, the new Health and Care Act 2022 came into effect in England from 1 July 2022. This requires the National Health Service (NHS) to consider climate change when making decisions. The legislation states that NHS organisations will have to consider and comply with the UK's Climate Change Act 2008, aiming to meet greenhouse gas emission targets and comply with the Environment Act 2021 which includes targets for improving the natural environment, including air quality. The NHS must also "adapt to any current or predicted impacts of climate change" (13). In Europe, the EU Eco-Management and Audit Scheme (EMAS) (14) helps organizations including laboratories to evaluate, report, and improve continuously their environmental performance, and the NGO Healthcare without Harm is producing a sustainable product index (15)

The only way to gain real traction on sustainability is to campaign for change and to educate about the environmental benefits and its cost-effectiveness. For example, it may not always be easy to convince those requesting tests that some of their requests are unnecessary. Communications are a hurdle to overcome too, as many parties are involved in the endeavour. Persistence is the key. Once a system for sustainability is in place, people tend to follow and implement it.

The purpose of this document is two-fold:

(i) to create an awareness that clinical laboratories have a carbon footprint.

(ii) to provide guidance on how laboratories can mitigate it.

In this document, we will attempt to give guidance on achieving greater sustainability through better ways to manage:

(i) Chemicals
(ii) Energy
(iii) Waste
(iv) Water

3. CHEMICAL STRATEGY FOR SUSTAINABILITY

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3.1. INTRODUCTON.

One of the first definitions of sustainability was attempted in the Burtland Report, published by the United Nations in 1987, stating that sustainable development implied meeting “the needs of the present without compromising the ability of future generations to meet their personal needs” (16). The definition proposed by the European Union (EU), however, is broader and considers a wide range of sustainability strategies, including human, environmental and economic aspects (17). As the atmosphere warms and the climate changes, one of the eight million species on the planet are at risk of being extinct; oceans and forests have been progressively destroyed and polluted. The EU responded to these challenges with the creation of the European Green Deal, which aims to transform the EU into “a fair and prosperous society, with a modern, resource-efficient and competitive economy that aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts” (18).

In recent years, there has been an increase in waste, including hazardous waste, due to industrialization, urbanization, economic development, and rising population. It is estimated that more than 1.3 billion tonnes of municipal solid waste were generated in 2012, with a prediction of 2.2 billion tonnes of waste in 2025 (19). In addition, this issue also has a profound social, economic, and environmental impact in Europe, where approximately 3 billion tonnes of waste are produced each year, of which 100 million tonnes are hazardous (20). Nevertheless, as healthcare waste is significantly more hazardous, it requires a different approach so that the risks to workers and the general population are reduced (19). It is estimated that 15% of healthcare waste is hazardous (infectious, toxic, or radioactive)(21), and that chemical or pharmaceutical waste represents 3% of all waste associated with healthcare (22). In high-

income countries, 0.5 Kg of hazardous waste per hospital per day are generated, in contrast to low-income countries, with 0.2 Kg (underestimated due to lack of separation of waste between hazardous and non-hazardous) (21). Thus, medical waste has become one of the most important pollutants worldwide and in Europe, affecting soil, water, and air quality. It is a priority for healthcare organizations to have multidisciplinary teams addressing sustainability issues (23).

Chemicals, although a type of hazardous waste, have enriched society and are ubiquitous in EU, with the European chemicals industry growing from €326 billion in 1995 to €615 billion in 2016 (24). Additionally, the global production of chemicals has been increasing, as well as the yearly import of manufactured goods to the EU - almost tripling between 2000 and 2015 - including from poorly regulated countries concerning chemicals. In fact, 3.4 tonnes of products per capital were imported in the EU in 2016, 20% of which were imported from China (25). Moreover, the share of chemicals produced in the EU has been decreasing, although it remains the fourth largest industry in the EU, with 30 000 companies and employing 1.2 million people and 3.6 million indirectly (26). Roughly 60% of the more than 100 000 chemicals in the EU market are considered hazardous to the environment and/or the human health, and 11.2% of EU's global chemical output is attributed to health and social work (25).

Regarding the risks related to chemicals, they can arise either from production, transport, use or disposal. Given the problem surrounding chemicals, it is a priority to manage them correctly and sustainably. Hazardous chemicals are a known contributor to health conditions in EU, being associated with cancer, neurodevelopment disorders, reproductive, metabolic, cardiovascular, and respiratory diseases (27,28). In general, the most vulnerable population subgroups will more likely develop pollution-related diseases (e.g., children of low socioeconomic status) (19). Furthermore, exposure to chemicals, even at low doses, can promote long-term health outcomes, such as, decreased fertility, lower birth weights and neuropsychiatric conditions in children – 10-15% of all births present neurobehavioral development disorders, attention deficit hyperactivity disorder (ADHD) and autism spectrum disorder have a widespread distribution (25). Additionally, there is an increasing number of different hazardous chemicals in human tissues and blood(26), which can induce toxic combination effects that are greater than the effects of each individual chemical separately (25). Combined exposure to hazardous chemicals has been associated with lower birth rates and reduced foetal growth (26). Moreover, there is a major economic impact due to exposure to endocrine disrupting chemicals, with €157 billion spent each year, and approximately €1.5 billion attributed to female reproductive diseases alone (25).

On the other hand, hazardous chemicals can cause stratospheric ozone depletion and affect ecosystems, flora, and fauna (19,28). Specifically, they

can decrease water and air quality, contaminate land, and affect insect pollinators, especially if used and/or discarded with disregard for current legal, scientific, and technical guidelines (27,28). Thus, chemical pollution is significantly contributing to the current global problem of climate change and loss of biodiversity (29). In the healthcare sector, disposal of untreated waste can promote the contamination of drinking water, groundwater, and surface water if landfills are not adequately built; inappropriate waste incineration can result in air pollution and ash residue, generation of carcinogenic dioxins and furans from chlorine-containing substances and spread of toxic metals from lead, mercury, and cadmium-containing materials (21). Recent data points to over 2.5 million possibly contaminated sites in Europe, with 14% known to be contaminated and in need of damage control measures (27). Therefore, new production processes and technologies, as well as new chemicals, must be sustainable throughout the product life cycle (29).

The economic toll concerning the contamination of the environment is significant, since there are very high costs of remediation related to the loss of drinking water, land, and fish stocks (25). The cost of healthcare waste disposal corresponds to 25% of the global healthcare sector spending in the United Sates (US) (30). In addition, decontamination of natural resources as well as buildings and infrastructure are extremely expensive - polychlorinated biphenyls (PBCs) contamination represented an expenditure of €15 billion between 1971 and 2018 in the EU (25).

The idea of Green Chemistry was born in the late 20th century as a response to the health, environmental and economic burden caused by hazardous chemicals, including toxic spill events. This concept is defined as “the design of chemical products and processes that reduce and/or eliminate the use or generation of hazardous substances” (25). Chemicals should be used and produced so that their contribution to society is maximized and their damage to the environment and society is minimized (26). Green chemistry and its principles can provide a strategy for reducing pollution, hazardous synthesis, and accident prevention, while evaluating the overall life cycle impact of a given chemical (25). Importantly, the effective environmental management of a clinical laboratory will lead to increased quality performance, as the two issues are intertwined.

The European Commission adopted the EU Chemicals Strategy for Sustainability on 14 October 2020. The Strategy is the first step towards a zero-pollution ambition for a toxic-free environment announced in the European Green Deal. The Strategy will boost innovation for safe and sustainable chemicals and increase protection of human health and the environment against hazardous chemicals. The strategy proposes a clear roadmap and timeline for the transformation of industry with the aim of attracting investment

into safe and sustainable products and production methods. https://ec.europa.eu/environment/strategy/chemicals-strategy_en

In line with the European Green Deal, the strategy strives for a toxic-free environment, where chemicals are produced and used in a way that maximises their contribution to society including achieving the green and digital transition, while avoiding harm to the planet and to current and future generations. It envisages the EU industry as a globally competitive player in the production and use of safe and sustainable chemicals. The strategy proposes a clear roadmap and timeline for the transformation of industry with the aim of attracting investment into safe and sustainable products and production methods.

Chemicals Strategy for Sustainability towards a toxic-free environment will

• Ensure better protection of human health and the environment from hazardous chemicals

• Boost innovation for safe and sustainable chemicals

• Enable the transition to chemicals that are safe and sustainable by design

It is a first step towards the Zero pollution ambition for a toxic-free environment announced in the European Green Deal.

There is evidence to support the beneficial effects of regulation in waste management. A recent study reported possible waste cost savings over $700 million over five years if all hospitals in the US instituted waste management strategies and of $2.7 billion over five years if single-use medical device (21)reprocessing was implemented (31). Furthermore, the EU chemicals acquis has been effective in reducing human and environmental exposures to hazardous substances targeted by EU legislation in the previous 3-4 decades, with some preliminary data pointing to substitution of these chemicals (21). The EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation has estimated cost savings of €100 billion over 25-30 years in benefits to the environment and human health (32). Thus, regulation to implement the safe and sustainable management of healthcare waste can prevent expenditure in adverse health outcomes and environmental impacts due to the release of chemical hazards (21).

Although 84% and 90% of Europeans are concerned about the impact of chemicals on health and the environment (26), respectively, the lack of training and knowledge in chemical products and their hazardousness may result in occupational and environmental safety issues. As such, it is crucial that professionals and students engaged in activities involving hazardous chemicals are trained accordingly (28). Concerning healthcare, a lack of knowledge and/or awareness in sustainability practices by clinical laboratory employees is the most common reported hurdle for sustainability in the healthcare sector (33).

Thus, laboratory-related scientific societies have a key role in providing continuing education and guidance.

Although sustainable structures and methods for sustainable healthcare are now well-defined regarding their goals in the social, economic, and ecological fields, there is a lack of consensus on the strategies to be implemented in clinical laboratories (33). In fact, a survey performed by the International Federation of Clinical Chemistry and Laboratory Medicine reported that most respondent laboratories had not addressed sustainability issues, and that there was a need for official guidelines on how to reduce their carbon footprint (34).

3.2. WHAT IS GREEN CHEMISTRY?

The Green Chemistry concept applies innovative scientific solutions to solve environmental issues posed in the laboratory. The concept of Green Chemistry was introduced in the late 1990s by Paul Anastas and John Warner. They developed the Twelve Principles of Green Chemistry (35). These principles can be grouped into "Reducing Risk" and "Minimizing the Environmental Footprint" which include the reduction of both the amount of hazardous chemicals in waste and the toxicity of those substances; improved efficiency of the production process; decreased resource use and greenhouse gas emissions; improved safety; and the economic and social aspects of chemicals (25).

The aim of Green Chemistry is to reduce chemical-related impact on human health and virtually eliminate contamination of the environment through dedicated, sustainable prevention programs. Green chemistry searches for alternative, environmentally friendly reaction media and at the same time strives to increase reaction rates and lower reaction temperatures.

DOZN™ Quantitative Green Chemistry Evaluator tool of Merck Sigma Aldrich is a quantitative, industry-first tool that uses the 12 principles of green chemistry for comparing the relative greenness of similar chemicals, synthetic routes, and chemical processes.

(https://www.sigmaaldrich.com/TR/en/services/software-and-digital-platforms/dozn-tool).

https://www.sigmaaldrich.com/TR/en/technical-documents/technical-article/analytical-chemistry/green-chemistry-principles

The Merck Sigma Aldrich company has 4 Categories of Greener Alternative Products fulfilling one of the four criteria below:

1. Re-engineered Products to improve their environmental footprint.
2. 12 Principles Aligned Products align with the 12 Principles of Green Chemistry.
3. Enabling Products help to make greener alternatives possible through enabling technologies.

4. Design for Sustainability (DfS) Developed Products demonstrate significant sustainability characteristics.

The concept of Green Chemistry, along with the EU strategy for a non-toxic environment, can be viewed as part of the global sustainability goals. Additional, safe, and sustainable-by-design chemicals is a pre-market approach that strives to deliver substances that minimize their health and environmental impacts (26).

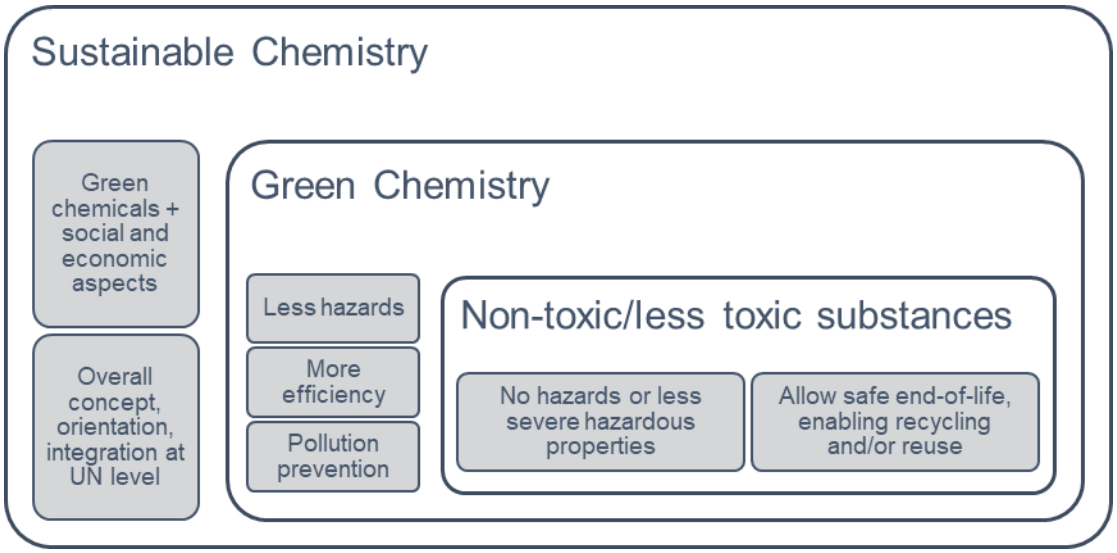

Figure 2. Relationship between the concepts of sustainable chemistry, green chemistry and non-toxic/less-toxic substances (26).

Concerning the strategies to promote sustainable chemistry in clinical laboratories, there are general approaches to both the management of waste and the selection and management of chemicals, as seen in Figure 2 and Figure 3.

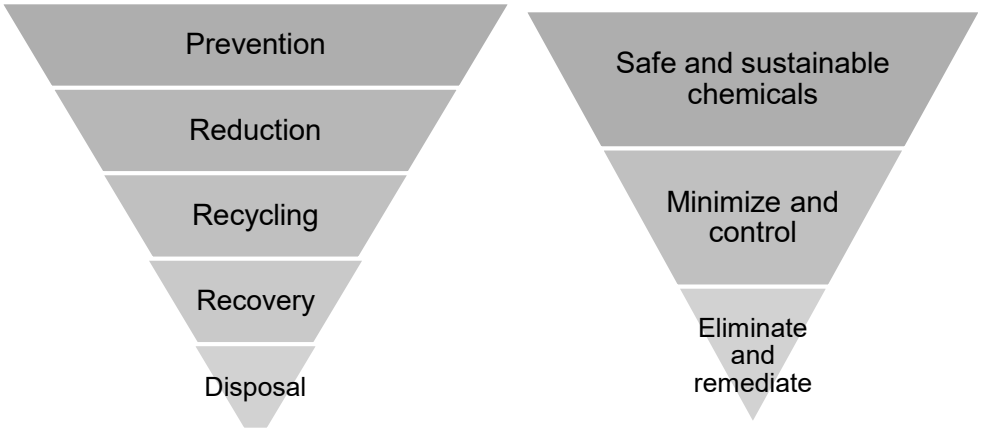

Figure 3. Hazardous chemical waste management hierarchy (26).

Eliminate/reduce or substitute hazardous chemicals:

- Eliminate chemicals whenever possible:
    - Exchange mercury thermometers and discontinue ethidium bromide use for gels.
    - Consider the development of solventless chemical reactions.
    - Use computer simulations as a substitute for experiments.
- Reduce quantities of harmful chemicals, reagents, and precursors if they cannot be excluded:
    - Use more efficient chemical reactions.
- Use green chemistry to substitute chemicals with less toxic alternatives:
    - Catsub – 300 examples of substitution of hazardous chemicals.
    - Cefic LRI toolbox – Risk assessment and toxicity testing.
    - CLEANTOOL – Database for alternative cleaning chemicals.
    - EC (2012) Guidance – Identify chemicals that could or should be; evaluate alternatives in terms of risk, technical requirements, and practical and cost considerations.
    - EPA- Design for the Environment Alternatives Assessments
    - German Column Model (Spaltenmodell) – Comparison of hazards and risks of different chemicals.
    - Green alternatives wizard – Potential substitutes for hazardous chemicals.
    - INRS – Identify potential areas of exposure in the workplace and compare chemicals.
    - Keki-Arvi – Risk assessment and avoidance.
    - OECD Toolbox – Alternatives assessment and general regulation, lists and methodology.
    - Stoffenmanager – Chemical exposure assessment and possible control measures, including substitution.
    - SUBSPORT – Alternative substances and technologies.

3.3. LEGISLATIONS.

The existing EU legal framework on chemicals, in particular the REACH and Classification, Labelling and Packaging (CLP) Regulations, are the strictest legislation in the world, regulating chemical substances, affecting industries throughout the world. The Chemicals Strategy suggests that they should be reinforced with targeted revisions of both Regulations to ensure that there is sufficient information on chemicals manufactured or imported into the EU.

Implementation and enforcement of European chemicals legislation is needed to ensure compliance for the whole life cycle of chemicals: production, placing on the market, release, and disposal. Currently almost 30% of the alerts on dangerous products on the market involve risks due to chemicals. Also, only one third of the registration dossiers of the chemical substances registered by industry under REACH are fully compliant with the information requirements.

The Commission will carry out audits on the enforcement systems of the Member States and make proposals to further strengthen the principles of 'no data, no market' and the ‘polluter-pays'.

Substances identified as of very high concern under REACH as well as those listed in Classification, Labelling and Packaging (CLP) Regulations as having chronic effect on health and the environment.

In order to prevent negative long-term effects, the exposure of humans and the environment to these substances of concern should be minimised and substituted as far as possible. The most harmful ones should be especially banned from consumer products and allowed only for proven essential societal use and where no acceptable alternative exist.

Chemicals-related legislations have more than 100 directives and regulations. This section pertains only to the most important documents.

- **United Nations (UN) Sustainability Development Goals:**

  3. Ensure healthy lives and promote well-being for all at all ages.

  6. Ensure availability and sustainable management of water and sanitation for all.

  9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

  11. Make cities and human settlements inclusive, safe, resilient, and sustainable.

  12. Ensure sustainable consumption and production patterns.

  14. Ensure availability and sustainable management of water and sanitation for all.

  15. Protect, restore, and promote sustainable use of terrestrial

ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

- **World Summit on Sustainable Development (WSSD):** achieve the environmentally sound management of chemicals and all wastes throughout their life cycle.
- **European Green Deal**
- **European List of Wastes (LoW)**
- **EU Waste Framework Directive**
- **Basel convention** on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.
- **Globally Harmonized System of Classification and Labelling of Chemicals (GHS),** formally adopted in July 2003 by the United Nations Economic and Social Committee.
- **EU Regulation on the registration, evaluation, authorization, and restriction of chemicals (REACH)**
- **Regulation on the Classification, Labelling and Packaging of hazardous substances (CLP)**
- **UN Environment Program on Mercury**
- **International Organization for Standardization (ISO):**
    - ISO 14000
    - SO 14001:2015
    - ISO 9000
    - ISO 15189
    - ISO 19011
- **Environmental, health and safety guidelines (EHS) from the International Finance Corporation (IFC)** on occupational health and safety.
- **Other EU documents:**
    - **Directive 91/157/EEC1** on restricting mercury in batteries.
    - **Directive 67/548/EEC** on the classification and labelling of a substance which is hazardous to the environment.
    - **Commission notice on technical guidance on the classification of waste (2018/C 124/01)**
    - **EU Waste Management Directive (EU) 2018/851** amending Directive 2008/98/EC

- **Directive 2011/65/EU** on restrictions in Electrical and Electronic Equipment (EEE).

3.4. HAZARDOUS CHEMICALS. HOW CAN LABS REDUCE HAZARDOUS CHEMICALS USE.

Chemical production is one of the most polluting, energy and resource-intensive sectors and is closely integrated with other energy-intensive sectors and processes. While the European chemical industry has already invested in improved manufacturing plants, the green and digital transition still requires significant investments for the sector. Novel and cleaner industrial processes and technologies would help not only to lower the environmental footprint of chemicals production but also to reduce costs, improve market readiness and create new markets for the European sustainable chemicals industry.

Energy efficiency must be prioritised in accordance with the ambition of the European Green Deal, and fuels such as renewable hydrogen and sustainably produced biomethane could play a decisive role for the sustainability of energy sources. Digital technologies – such as the internet of things, big data, artificial intelligence, smart sensors, and robotics – can also play an important role in greening manufacturing processes. In addition, chemical innovations can bring sustainable solutions across sectors to reduce the overall environmental footprint of production processes.

Chemicals are ubiquitous in our society and have been sources of improvement of human health and life expectancy, specifically in healthcare and clinical laboratories. However, they represent possible causes of adverse effects to human health and the environment because of their potential hazardousness (24,36). Thus, the definition and classification of hazardous chemicals is key to identify and prevent exposure to these substances, which can be done through labels and safety data sheets.

Definitions of hazardous waste differ according to the country, although in general, hazardous waste is defined as a material that is deleterious to human health or the environment that is no longer usable for its original purpose and is intended for disposal, but it is still hazardous (19,29). The risk can increase as waste composition changes (19). In the EU, hazardous waste is based on the Decision on the List of waste in conjunction with Annex III to the Waste Framework Directive. In clinical laboratories, chemical waste includes solvents and reagents, sterilants, disinfectants, batteries, heavy metals from medical devices, radioactive diagnostic material, and chemical mixtures (21).

There are several properties that can render chemicals hazardous, such as being explosive, oxidizing, highly flammable, flammable, irritant, harmful, toxic, carcinogenic, corrosive, infectious, toxic for reproduction, mutagenic, sensitizing, ecotoxic, or capable of releasing toxic or very toxic gases in contact

with water, air, or an acid, as well as chemicals that yield another substance with the characteristics listed above after disposal (37).

When addressing the hazardous potential of a chemical, there several aspects to be considered (38):

- Its physicochemical properties.
- The quantity produced/imported and used in each product application.
- Duration and frequency of exposure.
- Transformation and degradation products.
- Major impurities and additives.
- Likely pathways to the environment, environmental distribution and degradation or transformation.
- Duration and frequency of emissions to different environments and its respective dilution.
- Likely routes of exposure and absorption in humans.
- Geographical scale of exposure.
- Matrix dependent release of the chemical.
- Accurate exposure data availability.
- implemented or recommended risk management.

Concerning the environmental impact of hazardous chemicals, they can enter to the natural ecosystems either at extraction, manufacture, downstream use (e.g., at clinical laboratories) or through disposal/recycling//reuse of the substance (27). The assessment should include the potential effects on the aquatic, terrestrial and atmospheric compartments, as well as in the microbiological activity of sewage treatment systems and impacts via food-chain accumulation (38). Additionally, their impact varies according to the type and volume/concentration of the chemical; the affected environmental compartment (air, water, land); the duration of exposure (acute versus chronic); the timing of release into the ecosystem and the receptors (e.g., species) exposed and their sensitivity to the chemical (27). These assessments help to categorize a hazardous chemical and to define the concentration below which adverse effects in the environmental sphere of concern are not expected to occur - Predicted No-Effect Concentration (PNEC) (38). Furthermore, there are issues concerning reused chemicals in a circular economy, as this can increase the circulation of hazardous chemicals. An important class of chemicals are those determined as very persistent (resistant to degradation) since their indefinite stability promotes accumulation to harmful levels (25). Recently, combination effects of chemicals have gained relevance, which consist of exposure at low concentrations of different hazardous chemicals, even if all substances are below the PNEC (39).

The classification list of hazardous substances and chemicals can be found in the “Regulation on the Classification, Labelling and Packaging of hazardous substances (CLP)” EU document (40) and the EU Regulation on the registration, evaluation, authorization, and restriction of chemicals (REACH). The European Waste Catalogue classifies waste from human or animal healthcare and/or related research and further divides it into sections applicable to chemicals in clinical laboratories (41):

- 18 01 Wastes from natal care, diagnosis, treatment, or prevention of disease in humans
- 18 01 06 Chemicals consisting of or containing hazardous substances
- 18 01 07 Chemicals other than those mentioned

According to the ECHA/CLP inventory, there are over 120 000 registered chemicals and 2 327 hazardous substances out of 4 231 that have a harmonized classification of “harmful to the aquatic environment” (27). In Europe, the most common soil contaminants include heavy metals, mineral oils and polyaromatic hydrocarbons (PAH) (27). The following table includes the most commonly registered chemicals in REACH (29):

Substance	Number of registrations
Ethanol	707
Calcium dihydroxide	577
Iron	535
Ethylene oxide	526
Ethylene	450
Charcoal	413
Aluminium oxide	412
Aluminium	385
Styrene	358
Methyloxirane	355
Silicon Dioxide	339
Propene	335
Calcium sulphate	325
Titanium dioxide	316
Sodium hydroxide	310
Ethane-1,2-diol	306
Silicon	301
Methanol	284
Calcium oxide	278
Propane-1,2-diol	276

Table 1. Most commonly registered substances in REACH.

Moreover, according to the Directive 2011/65/EU regarding medical devices, there are restricted substances which have a maximum concentration tolerated by weight in homogeneous materials, namely, lead (0.1%), mercury (0.1%), cadmium (0.01%), hexavalent chromium (0.1%), polybrominated biphenyls (PBB) (0.1%), polybrominated diphenyl ethers (PBDE) (0.1%), bis(2-ethylhexyl) phthalate (DEHP) (0.1%), butyl benzyl phthalate (BBP) (0.1%), dibutyl phthalate (DBP) (0.1%) and diisobutyl phthalate (DIBP) (0.1%) (42). Mercury has a high toxic potential to both humans and wildlife, especially in the form of methyl mercury; however, the use of this heavy metal is declining globally and, in the EU, due to the availability of mercury-free alternatives and increasing regulatory restrictions for its use (43). In Europe, mercury is used in the chemicals sector, lighting, switches, and electrical controls, measuring and control equipment, dental amalgam, batteries and in chlor-alkali plants (43).

The Environmental, Health and Safety (EHS) group at Pfizer Global Research and Development initiated a project to assess the suitability of common solvents based on criteria of (i) Worker Safety, (ii) Process Safety, and (iii) Environmental and regulatory considerations. The recommendations were published in Green Chem., 2008,10, 31-36 (DOI: 10.1039/B711717E).

3.5. OBJECTIVES.

The aim of the module on “Green Chemistry” is to educate and inform about the hazardous chemicals and effective ways to decrease the hazardous chemicals in laboratories.

- Standardization of green chemistry and hazardous chemicals sustainability processes in clinical laboratories.
- Encouragement of laboratory medicine professionals to implement green chemistry and hazardous chemicals-related sustainability measures.
- Promote the increase in hazardous chemicals data from clinical laboratories, including new insights and outcomes.
- Support changes in community attitudes and behaviours concerning chemicals, specifically among healthcare professionals.
- Promote educational programs in green chemistry.
- Strive to reach a significant number of European countries and clinical laboratories regarding chemical-related sustainability actions.
- Prevent air, water, and soil contamination with hazardous chemicals and respective environmental, health and economic impacts.
- Improve occupational health.
- Increase resource efficiency.
- Reduce hazardous chemical waste collection, treatment, and disposal expenditures.

- Promote sustainable procurement systems.
- Indirectly increase demand and innovation for safe and sustainable chemicals

Procurement:

Healthcare represents approximately half of the EU government expenditure, with more than 15 000 hospitals (44). Therefore, clinical laboratories can play a role in shifting supply and demand of chemicals towards green alternatives by adopting a green purchasing policy, which includes the selection and acquisition of products that minimize environmental impacts over their entire life-cycle: use recyclable, recycled, less toxic and locally produced chemicals whenever possible.

Chemical inventory management and storage:

- Do not store chemicals in the fume cupboard, specially without a proper seal.
- Maintain and review the chemical inventory to avoid over-purchasing and guarantee that expired chemicals are disposed of adequately.
- Date and use chemicals and reagents as first in, first out
- Purchase the minimum the amount of chemicals required.
- Share chemicals and reagents:
    - Increase collaboration between clinical laboratories.
    - Host chemical share/swap events.
- Chemical leasing or chemicals-as-a-service: a new business model in which the supplier contracts to provide only the amount of chemicals needed, which results in health, environmental and economic benefits for both sides (19).

Reduce and Recycle Solvents:

Reduce the use of organic solvents by recycling them, which reduces exposure and chemical waste – many solvents (acetone, acetonitrile, xylene, alcohol, formalin) can be efficiently distilled back to +99% purity through on-site recyclers and vendors (34):

- Xylene, alcohol, and formalin may be recycled by the use of a CBG Biotech Supreme Solvent Recycler (Thermo-Fisher Scientific).

Small volumes need to be purchased intermittently to replace the dead volume lost during the recycling process, which is also economically favourable.

Chemical waste management:

- In cases where exclusion of hazardous chemicals cannot be done, it is key to have dedicated management and safe and efficient separation of waste (19).
- Chemical waste disposal must be as safe as possible, ensuring that it is treated as close as to its source as possible (20).
- Label, store and dispose of hazardous chemicals according to procedures and considering specialized clinical laboratory waste; preferably, write Standard Operating Procedures (SOPs) for handling chemical waste/hazardous chemicals.

Rational number of tests:

Laboratory testing costs constitute approximately 3% of all clinical costs, with a common strategy to reduce healthcare expenditure being a random reduction of laboratory budgets and unnecessary tests (45). Thus, auditing requests of laboratory tests to identify test redundancy can decrease the number of reagents and hazardous chemicals used. The World Health Organization (WHO) published an Essential In Vitro Diagnostics (IVD) List, which identified 35 test categories of general IVDs that can be used for the diagnosis of several common diseases and 27 test categories of IVDs for the management of HIV infection, tuberculosis, malaria, hepatitis B and C, syphilis, and HPV infection (46).

Policy:

- Institute an environmental policy, provide documentation and a staff training program on environmental issues and best practices.
- Promote audits to evaluate progress before and after sustainable measures.
- Appoint an environmental manager and obtain support from senior management by advocating for corporate responsibility, financial benefits and increased laboratory reputation among customers and the community.
- Set the example through senior members and provide employee feedback.
- Implement control measures to avoid or minimize the release of hazardous substances into the work environment and the number of exposed employees. Train workers in the use of hazardous chemicals, safe work practices and appropriate use of Personal Protective Equipment (PPE).

Advocacy:

The community in general supports environmental initiatives. Engage groups associated with the clinical laboratory, such as patients, contractors, colleagues, and the government.

3.6. ACTIONS.

- Publication of action plans and guidelines concerning hazardous chemicals and green chemistry, which include surveys and checklists.
- Training of the 49 National Society Representatives to become Green Lab Delegates/Ambassadors on the subject of green chemistry and hazardous chemicals.
- Promote meetings with the National Societies regarding hazardous chemicals and sustainability measures.
- Create workshops on green chemistry for the whole EFLM Community.
- Create a certification for Green Labs, including sustainable chemistry.

4. STRATEGIES FOR ENERGY CONSERVATION AND SUSTAINABILITY

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4.1. INTRODUCTION

Clinical laboratories use 3–6 times more energy per m^2 than a typical office building. This is due to the permanent functioning of the specialized laboratory equipment, but also to ventilation systems (about 50–80% of energy consumption), as well as to the need for temperature and humidity control (10).

The transport of samples, pre-pre-analytical and pre-analytical phases are other areas of reflection to reduce the CO_2 footprint of clinical laboratories (47,48).

In order to implement good environmental practices, it is important to introduce an Environmental Management System and to define an appropriate sustainability policy. Data mining and artificial intelligence can contribute to maximise energy efficiency, measure, and control the carbon footprint. This offers sustainable solutions and reduces costs (49). However, transformation towards a sustainable laboratory starts already with simple and easy-to-implement reductions made by laboratory staff, where senior management can usefully take a leading role and set the example.

Environmental improvement should be based on the 3R concept to reduce (reduce the consumption of energy, natural resources, and unsafe products), reuse (reuse items as much as possible before replacing them) and recycle (processing of used materials to new products, thus preventing waste, reduce the consumption of fresh raw materials, energy usage, air, and water pollution) (9).

When estimating the clinical laboratory carbon footprint produced by the energy consumption, -and putting aside specific laboratory instruments- laboratory infrastructure should also be considered, like the heating, ventilation, and air conditioning (HVAC) system, lighting/shading system, and data processing systems (computers). These four groups of energy consumers realize their

environmental impact not only by consuming energy (i.e., electricity and gas), but also water and creating waste, as illustrated in Figure 4 below (50).

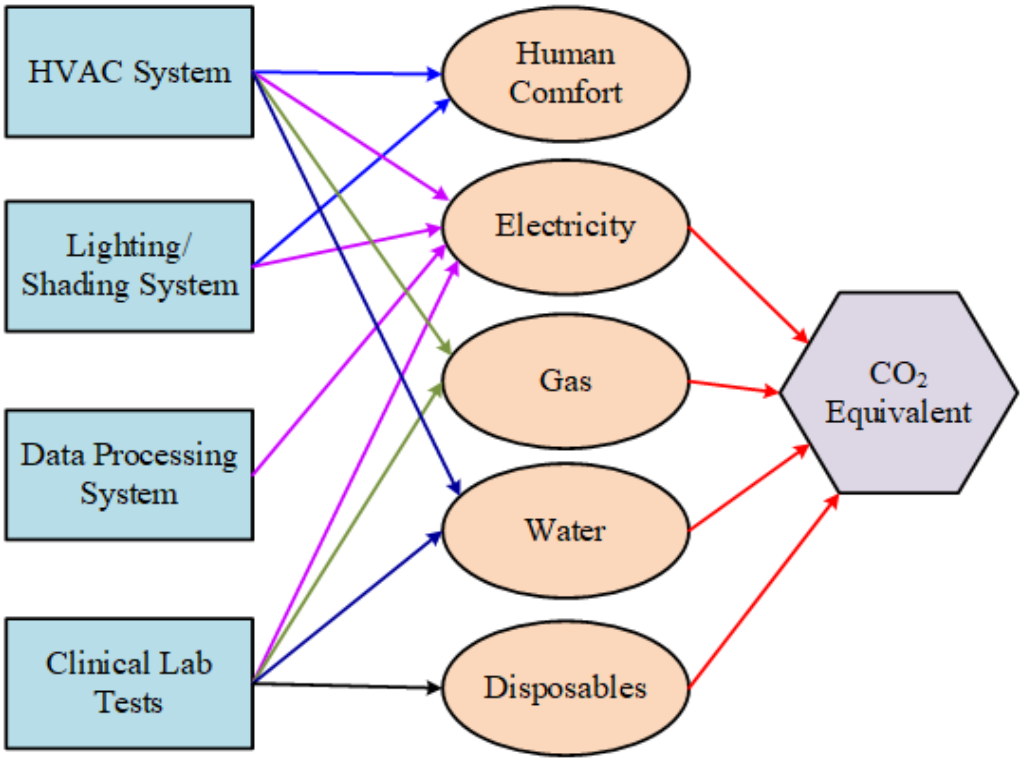

Figure 4. Individual energy consumers within a clinical laboratory and their impact on carbon footprint (50).

4.2. IMPLEMENTATION OF GOOD ENVIRONMENTAL PRACTICE REGARDING ENERGY CONSUMPTION

Targets for sustainable practices in clinical laboratories with regard to management of energy consumption may be defined as follows (10,49):

- Reduction of energy consumption in the laboratory's workflow.
- Reduction of gasoline consumption by laboratory logistics and staff:
  - If using vehicles for transport of samples, select fuel-efficient, and their routes and review regularly usage.
  - Motivate laboratory personnel to use public transport, carpools or bicycles when coming to work, in order to reduce their individual carbon footprint.
  - Invite suppliers to join laboratory's efforts to introduce good environmental practices.
- Energy-efficient and environmentally friendly design of laboratory/hospital buildings:
  Apply good environmental practices when renovating or constructing a new laboratory building. Engage LEED (Leadership in Energy and

Environmental Design) certified architects to ensure that best-in-class building strategies and practices are implemented (51).

- Use of renewable energy sources when and where possible (wind, solar photovoltaics, and solar thermal energy).
- Collaboration between hospital buildings and laboratory networks for resource sharing.

4.2.1. HOW CAN LABS REDUCE ENERGY CONSUMPTION?

4.2.1.1. SWITCH OFF

One of the simplest methods for reducing energy consumption is to switch off lights, computers, instrumentation, and equipment at the end of the day or when not in use. This is especially important with those that have a heating or cooling element as these are high energy consumers. It can be more easily implemented by introducing a 'traffic light sticker system' on electrical equipment. Agreement by management and senior staff on which equipment can be turned off will encourage all users. For example, Green – switch off equipment when you are finished using it; Orange – check with senior staff on whether it can be turned off after use/end of day; Red – must remain on (52–55).

4.2.1.2. SMART TECHNOLOGY

- Installing sensor lights throughout corridors and infrequently used areas or storerooms.
- Replace light fittings with more efficient ones when and where possible and switching from fluorescent bulbs to LED. LEDs provide the same light intensity, have longer life span, and use 50% less energy, which will have a cost saving element, too.
- Use natural light as much as possible, discourage habitual use of artificial light when there is sufficient natural light. Also, task lighting, which illuminates specific work areas and modular lighting that follows modular laboratory furniture, benches, biosafety cabinets etc, should be considered (53,54,56).
- Use solar power, sustainable biofuel, combined heat, and power systems, could be used to supplement the electricity and heat requirements (57).
- Ensure energy saving or sleep mode is active on computers, printers, and scanners so as to increase energy saving throughout the working day. Do not use screensavers as these require processing power and memory, which in turn uses energy (53,58).

4.2.1.3. THINK TWICE

- Reduce and discourage staff from printing, encourage printing only where necessary.

- Reducing the number of emails being sent, especially those with attachments. Most are unaware that the average email has a carbon footprint of between 4–50 g CO2 depending on attachments. Unsubscribe to emailing lists of no value or interest (59,60) .

4.2.1.4. TIMERS

- Install timers on equipment, for example water baths and heating blocks. Timers both ensure the equipment is ready for use when needed and does not remain on long after the equipment has been used.

4.2.1.5. FUME HOODS AND BIOLOGICAL SAFETY CABINETS (BSC)

- Shutting the sash on fume hoods when not in use as the fan on these continuously pulls in heated or conditioned air from the room. These fume hoods can consume as much energy as several houses per day (56,58).
- Biological safety cabinets (BSC) can be switched off when not required or at the end of day as appropriate. These are energy intensive pieces of equipment using approximately half the energy of a house per day. Ensure any small appliances used inside fume hoods or BSC are also powered off when not in use. If using UV light as a method of decontamination, install a timer and only run when laboratory is empty to prevent UV damage to staff. Long term running can degrade products over time, so best practice is to run for 30 minutes, as this is sufficient to decontaminate the cabinet and, in most circumstances, UV decontamination is not required (53,61–63).

4.2.1.6. REFRIGERATORS AND FREEZERS

- Keep refrigerators and freezers organized to reduce opening times, thereby saving energy and time.
- Audit regularly what is stored to prevent a build-up of items no longer required.
- Defrost routinely freezers and clear out regularly items stored to ensure they run efficiently and to reduce energy consumption. Fill empty spaces with empty storage boxes or ice packs to prevent over icing.
- Change regularly filters that need changing, clean exposed refrigeration coils of refrigerators and freezers and clean the door sealing.
- Where possible -80°C can be increased to -70°C without adverse viability or compromise of stored items. This change has shown to have energy savings of up to 30% (52,53,58).

4.2.1.7. WASTE

- Autoclaves should be run as efficiently as possible. This might include a two-streamed route where items are sent for autoclave or dishwashing as appropriate. Autoclaves should only be run when full; this may mean sharing loads within departments. Setting up a schedule might help to coordinate runs. Ensure laboratory or clinical waste being sent for autoclave is necessary. This should be reviewed periodically to ensure practices are current.

4.2.1.8. AIR CONDITIONING

- Ensure windows are not open or space heaters are not used while air conditioning units are in operation. Temperature and humidity controls should be adjusted relative to seasonal demands. Close doors in rooms where AC is being used (56).

4.2.1.9. EQUIPMENT AND INSTRUMENTATION

- During the tendering process, choose equipment and instrumentation that carry an energy star rating and insignificant air-conditioning or heating requirements. Energy efficient purchasing (star rated appliances) of new equipment and instrumentation is essential.
- Managers should insist that suppliers take back packaging materials for reuse or recycling after supply of instruments and equipment. They are also obliged to take old appliances for recycling under EU waste electronics (WEEE) regulations. Ensure all equipment is made safe and decontaminated where necessary.
- Where possible, new equipment should be locally purchased to reduce the carbon footprint associated with delivery and supply.
- If possible, include a green element to procurement (53,58,64).

4.2.1.10. REAGENTS AND CONSUMABLES

- Reagents and consumables should be sourced and manufactured as locally as possible to reduce carbon footprint associated with transport.
- Products should be bulk bought, especially commonly used items across departments. This may have both a cost and energy saving.
- Discussions with suppliers to reduce packaging, especially difficult to recycle or non-recyclable packaging like polystyrene (10,52).

4.2.1.11. “SHARING IS CARING”

- Smaller departments or laboratories might consider equipment sharing instead of purchasing their own. Examples where this can be effective is autoclaves, freezers, printers, fume hoods, thermal cycles, water

filters/deionizers. All these items are easily shared with minimal planning and rotas (52,54).

4.2.1.12. SAMPLE TRANSPORTATION, PRE-PRE-ANALYTICAL AND PRE-ANALYTICAL PHASES

- When possible, use of alternatives such as cycling or small cars for transport of sample and laboratory materials over short distances.
- If possible, use hybrid or electric vehicles to transport samples and laboratory materials.
- Explore future alternatives such as drones' transportation, a solution coming in several fields of healthcare (65)

5. WASTE MANAGEMENT STRATEGIES

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Of the total amount of waste generated by health-care activities, about 85% is general, non-hazardous waste. The remaining 15% is considered hazardous material which may be infectious, toxic, or radioactive. Measures to ensure the safe and environmentally sound management of health care wastes is essential to prevent adverse health and environmental impacts from such waste (66).

5.1. WASTE MANAGEMENT STRATEGIES

Laboratory wastes are those wastes which have come in direct contact with pathogenic organisms, or body fluids and other items that are used in the laboratory.

Medical waste is usually either dispatched to landfills or incinerated. Landfills leach harmful chemicals into the ground and water supply. The burning of medical waste generates atmospheric pollutants such as dioxins, furans, and particulate matter. Laboratories have a societal obligation to reduce and better manage their waste. To achieve this, there is a need to create combined pressure from the laboratory on the *in vitro* diagnostics (IVD) industry, professional bodies, and the regulatory authorities. Our aim is to encourage environmental performance improvement beyond mandatory compliance, driven by motivation rather than regulatory compulsion.

The management of clinical laboratory wastes should be premised upon the three pillars of good environmental practices, namely, to **Reduce, Reuse and Recycle**. The best strategy for managing laboratory wastes should be considered from the time of purchase. The overriding principle governing the prudent handling of laboratory waste is that no activity should begin unless a plan for the disposal of non-hazardous and hazardous waste has been formulated. Application of this simple principle ensures that local and national regulatory requirements for waste handling are met, and unexpected difficulties are avoided such as the generation of a form of waste (e.g., biological, chemical, radioactive) that the institution is not equipped to deal with (66–68).

While the impact of each source of waste may seem relatively minor, their potential cumulative effect on the environment can be significant. Waste production needs to be measured and managed. Minimizing the amount of waste produced in your laboratory can help you get a better handle on your waste management. Waste production needs to be measured and managed. Laboratories should aspire to manage their wastes in the following ways:

(i) Reduce its quantity
(ii) Reuse or redistribution of unwanted, surplus materials.
(iii) Treat and/or recycle materials within the waste; and
(iv) Dispose through incineration, treatment, or land burial.

One of the ways wastes can be minimised is by ensuring that only tests that are necessary are performed. It also makes good economic sense. Test requests should be vetted to ensure this. Test reduction also makes good economic sense.

5.2. WASTE CATEGORIES AND THEIR MANAGEMENT

Clinical laboratory wastes can be classified in several ways. We wish to propose the following categories:

- **Non- biological solids** such as plastics, packaging, e-wastes (electrical and electronic wastes) and miscellaneous solid wastes such as paper.
- **Biological wastes:** this category includes glass, sharps, etc.
- **Chemicals:** liquid, organic, solids; include disinfectants, solvents, detergents used for laboratory purposes, batteries, and heavy metals from medical equipment such as mercury from broken thermometers. **The management of Chemical waste will be discussed in the section on Chemicals of this document**

5.2.1. MANAGEMENT OF NON-BIOLOGICAL SOLIDS

5.2.1.1. PLASTICS (69–76)

Plastic pollution has become one of the most pressing environmental issues. Globally, it is estimated that the production and incineration of plastic pumped more than 850 million tonnes of greenhouse gases into the atmosphere in 2019. By 2050, those emissions could rise to 2.8 billion tonnes, a part of which could be avoided through better recycling (69).

Single-use plastics account for about 40 per cent of the plastic produced every year. Many of these products, may persist in the environment for hundreds of years. Besides littering, plastic also pollutes through the release of compounds used in its manufacture. The biomedical sciences are a particularly high-volume consumer of especially single-use plastics. Indeed, some areas of science such as molecular biology have grown up in an era of single-use plastic. (72)

Microplastics i.e. tiny plastic particles, come from many sources and are ubiquitous. They enter into human beings via food and water, as well as breathing them in. Microplastics have been shown to harm wildlife and to damage human cells in the laboratory (71).

REDUCED Use of Plastics

Substitutes for Plastics: Labs can reduce their consumption of plastics by choosing substitutes for plastics, where feasible. to glass. Glass substitutions have been found to be effective for plastic items such as plastic petri dishes, bottles of various shapes and sizes, pipettes, and pipette tips (with metal ones), sample tubes, vials, baskets, Falcon tubes, test tubes and weigh boats.

Equipment and Reagents: The reduced use of plastics can also be achieved from the time of tendering for equipment and reagents. Choose equipment from IVD companies that:

- Produce equipment with reduced plastic content.
- Supply products with reduced packaging and/or environmentally friendly packaging e.g. purchase bagged falcons.
- Are willing to take back shells of used equipment for future use.
- Allow for reusable plastic accessories e.g., reuse original cuvette racks.

At the time of tendering for diagnostic reagents, are willing to take back packaging and used plastic reagent containers

In addition, reducing the number of suppliers or buying through a consolidator, thereby reducing number of deliveries helps the environment.

REUSE of Plastics

- Labs should reuse as many items as possible. Re-usable items can have comparable performance to single-use items materials.
- Where possible consider the following items for reuse: pipette tip boxes, pipettes, and pipette tips when aliquoting, weigh boats, gloves (decontaminate with ethanol), tubes and cuvettes (with a rinse between) beakers or tip-collecting container.
- Labs should substitute disposable plasticware even in sterile procedures e.g. by choosing glass tissue culture dishes instead of disposable, plastic dishes. However, if there is concern, consider reuse only for situations where sterile procedure is not necessary, such as bench work.

RECYCLING of Plastics

In Europe, energy recovery is the most used way to dispose of plastic waste, followed by recycling. Some 25% of all the generated plastic waste is landfilled. Half of the plastic collected for recycling is exported to be treated in countries

outside the EU. Globally, researchers estimate that the production and incineration of plastic pumped more than 850 million tonnes of greenhouse gases into the atmosphere in 2019. By 2050, it is estimated that those emissions could rise to 2.8 billion tonnes, a part of which could be avoided through better recycling (69).

Usually, laboratory waste plastics are bagged and “autoclaved” – an energy- and water-intensive sterilization process often using pressurized steam – and then they are sent to landfill. But not all plastic waste is too contaminated to recycle (72,75). Kuntin (75) and his colleagues developed a “decontamination station” with a 24-hour soak in a high-level disinfectant, followed by a rinse for chemical decontamination. They also buy plastics that would be easier to recycle. As a result of these measures, they have reduced the plastic they were previously sending to landfill by about a ton a year. They have worked out how they can bulk buy whenever possible, to cut down on packaging waste, for example.

Plastics that can most commonly be recycled are polystyrene (PS), polypropylene (PP) and high-density or low-density polyethylene (HDPE/LDPE). Commonly used consumables such as centrifuge tubes are made of PP, while culture dishes and flasks are usually made of PS. HDPE and LDPE are most commonly found in lids.

Recycling non-hazardous plastic waste is also becoming an option for labs. Many waste haulers are starting to accept non-hazardous plastic waste from labs. Several vendors offer recycling programs for their products. (EUROPEAN RECYLERS (77). Polycarbin (78) have developed a circularity concept for laboratories to recycle plastics and it is important that diagnostic laboratories start to assess the feasibility of recycling plastics.

Alternatives to Current Plastics

Several companies have been working to develop plastics that are made from renewable and biodegradable sources. These include BASF and NatureWorks (Innetonka, Minnesota, USA). BASF has developed a compostable polyester film called “Ecoflex®” and are making and marketing fully biodegradable bags, “Ecovio®,” made of this film along with cassava starch and calcium carbonate. None of these, however, are in widespread use.

5.2.1.2. PACKAGING

Packaging materials are items such as Styrofoam, cardboard, paper. They contribute much of the excess waste. Laboratories can therefore:

- Negotiate with suppliers to take back and reuse packaging materials.
- In addition, laboratories can also negotiate with suppliers to reduce the volume of waste cardboard and plastic that is incorporated in the

packaging of their products. However, this cannot be changed without going through due regulatory process.

- Invest in a Styrofoam compressor. The compressed product can be used for other purposes.

RECOMMENDATION: This group calls for an amnesty period agreed by all the regulatory authorities globally to allow companies to review and refine their packaging strategies to minimize waste through a simplified documentation process. This would allow all manufacturers to contribute to this effort.

5.2.1.3. E-WASTE (ELECTRICAL AND ELECTRONIC WASTES) (79,80)

It is estimated that 57.4 Mt (Million Metric Tonnes) of e-waste was generated globally in 2021. Europe has by far the highest collection and recycling rate at 42.5%. There is over **347 Mt** of unrecycled e-waste on earth in 2022 (79). E-waste does not biodegrade, and therefore will accumulate wherever it is dumped. Landfilling e-waste is harmful to the environment because of toxins such as mercury, lead, cadmium, nickel, beryllium, and arsenic can leach into the soil and water course and become harmful to human health.

Medical equipment no longer in use, fluorescent tubes, batteries, phones, computers, etc. should be recycled or disposed of in accordance with local regulations. A paper that reviews the approaches for both the laboratory and the manufacturers outlining a 10-point plan has been published by Cambridge Design (80). Labs should endeavour to **buy environmentally friendly electronics:** look for products labelled Energy Star or certified by the Electronic Product Environmental Assessment Tool (EPEAT).

5.2.1.4. RECOMMENDED ACTIONABLE MEASURES FOR IVD MANUFACTURERS

- ***Green products and labelling (also** called environmental labels, eco-labels):* Green products may be defined as products that contain recycled materials, reduce waste, conserve energy or water, use less packaging, and reduce the amount of toxics disposed or consumed. Manufacturers should subscribe to a green labelling model such as has been introduced in the EU where domestic appliances have an energy electrical technology has a rating from A to E based on agreed criteria.
    - ***Hardware:*** From a hardware perspective more consideration should be given to extending the life of equipment whether through a refurbish/recycle model on site with longer replacement times and/or through cannibalization initiatives that use at the minimum the skins of pre-used instruments.

- ***Software:*** Obsolescence of software often leads to the introduction of new hardware. We call on manufacturers to look at future proofing their products that will allow new software with Artificial Intelligence (AI, machine learning) to be used without replacing the total instrument.
- ***Microscale chemistry:*** Scaling down test procedures to a practical minimum reduces the total amount of waste generated. It also has safety and cost benefits.

5.2.2. MANAGEMENT OF BIOLOGICAL LAB WASTE (81,82)

Adapted from the protocols of the University of Connecticut and the University of North Carolina in Chapel Hill:

5.2.2.1. DEFINITION AND DESCRIPTION OF BIOLOGICAL WASTE

Laboratory biological waste may be defined as infectious or potentially infectious pathological waste, and the receptacles and supplies generated during its handling and/or storage. **Biological waste** includes:

- Liquids: cell culturing media, supernatant, blood, or blood fractions (serum), etc. which contain viable biological agents.
- Any part of the human body, tissues, and body fluids, including those not infectious.
- Any part of an animal infected or potentially infected with a communicable disease.
- Non-sharp, solid laboratory waste (empty plastic cell culture flasks and petri dishes, empty plastic tubes, gloves, wrappers, absorbent tissues, etc.) which may be, contaminated with viable biological agents.
- All sharp and pointed items used in medical care, diagnosis, and research.
- Laboratory glassware which is thought to be contaminated with hazardous biological agent.
- Any material collected from a spill of infectious or chemotherapy waste.
- **Waste mixed with infectious waste** that cannot be considered as chemical hazardous waste or radioactive waste.

5.2.2.2. DISPOSAL PROCEDURES

Liquid waste

Biological liquid waste can be poured down the drain (sanitary sewer), under running water **after it has been decontaminated** by autoclave or chemical

means. The sink should be rinsed well and disinfected after the disposal procedure.

Chemical decontamination: This may be achieved using PRESEPT™, a biocidal disinfectant based on the action of NaDCC (troclosene sodium). It provides protection against all organisms including MRSA, HIV, Hepatitis B and Herpes viruses. The denatured blood may be discarded via a sluice or laboratory sink with plenty of water. Any solids that are too large for the laboratory sink can be disposed of via biological waste.

Sharps waste

- Some sharps containers may melt if autoclaved, in which case chemical decontamination of the contents should be used. For chemical decontamination, the disinfectant shall be an equivalent of the US EPA registered tuberculocidal agent such as standard household bleach diluted to the final concentration of 10%. Fill with the appropriate dilution of disinfectant and let stand over-night. Empty the liquid, seal and label receptacle and put in box-bag unit.
- Alternately, untreated sealed sharps containers may be placed in the box-bag units with other untreated biological waste. The institution's address must be affixed to each sharp's container, indicating whether it is treated or untreated, that is placed in the box-bag unit.

Non-sharps

The acceptable methods for disposal are as follows:

- Biological waste decontaminated by an autoclave, chemical disinfection or other appropriate decontamination method can be labelled and disposed of as non-biohazardous/non-infectious waste in regular trash.
- If autoclave is available, autoclave the waste in an autoclave bag, affix autoclave indicator tape and place in an autoclave safe tray. After autoclaving and the bag has cooled, drain off any remaining liquid and place the sealed waste in the box-bag unit for pickup. Do not pour liquefied agar media down the drain. **Do not autoclave containers or other receptacles containing bleach.** The combination of bleach and residual cotton and oil (improperly cleaned autoclaves) may result in an explosive combustion within the autoclave.

Mixed waste: Follow the formula below to determine which waste stream.

Biological + Hazardous Chemical = Chemical Waste

5.2.2.3. STORAGE, LABELING AND TRANSPORT OF BIOLOGICAL WASTE

Storage: Biological waste must not be allowed to accumulate. It should be decontaminated and disposed of daily or on a regular basis. If the storage of contaminated material is necessary, it must be done in a rigid container away from general traffic and preferably in a secured area. Treated biological waste, excluding used sharps, may be stored at room temperature until the storage container or box-bag unit is full, but no longer than 48 hours. It may be refrigerated for up to 1 week from the date of generation. Biological waste must be dated when refrigerated for storage. If biological waste becomes putrescent during storage it must be moved offsite within 24 hours for processing and disposal. Sharps containers may be used until 2/3 to 3/4 full at which time they should be decontaminated, preferably by autoclaving, and disposed of as regulated medical waste.

Labelling of Biomedical Waste:

- Each individual bag or sharps container should be labelled with the institution's address, the generator's building, and room number. Indicate whether the waste in the box is treated or untreated.
- Non-biohazardous/non-infectious waste should be tagged with labels.
- Autoclave indicator tape should be used as evidence of decontamination.

Transport: The transport of biological waste outside of the laboratory, for decontamination purposes or storage until pick-up, must be in closed leak-proof containers that is labelled "biohazard". The transport of regulated medical waste or biohazardous biological waste through public streets must comply with government transportation regulations

5.2.2.4. DECONTAMINATION BY AUTOCLAVING

Steam autoclaving usually is considered to be the method of choice for decontaminating cultures, laboratory glassware and other small items known to be contaminated with infectious agents. The location of the autoclave within the laboratory minimizes storage and transport problems. Autoclaved waste can be disposed of as general waste.

Protocols for steam sterilization may vary with different laboratories. A written operating procedure should contain, at a minimum:

- Set the parameters, determined from testing, which provide consistent treatment such as exposure time, temperature, and pressure.

- Identify the standard treatment containers and placement of the load in the steam treatment unit.
- Provide for and conduct an ongoing program of training for all users.
- Provide for a quality assurance program to assure compliance with the biological waste management plan.
- A written log should be maintained for each steam treatment unit.

Biological waste should be subject to steam treatment of sufficient temperature, pressure, and time to demonstrate a minimum Log 4 kill of *Bacillus stearothermophilus* spores placed at the centre of the waste load. Waste shall not be considered treated if the tape or equivalent indicator fails to show that a temperature of at least 250 degrees F (121 degrees C) was reached during the process. The effectiveness of sterilization should be tested with spores of *Bacillus stearothermophilus* at least every 40 hours of operation.

6. WATER CONSERVATION STRATEGY FOR SUSTAINABILITY

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6.1. INTRODUCTION

The water crisis is identified as the most serious global risk for the coming decade (83). The sixth Sustainable Development Goal of the United Nation's 2030 Agenda relates to water and emphasizes the importance of water management in sustaining humankind (84). Worldwide, clinical laboratories consume a lot of water (four to five times more water than commercial buildings of a similar size) to meet process and cooling loads, among other requirements (10,85,86). Although water conservation is ignored, overlooked, and often misconceived as effectively limitless and costless, it represents the key aspect of sustainable laboratory. Water conservation is defined as any action that reduces the amount of water withdrawn from water supply sources, reduces consumptive use, reduces the loss or waste of water, improves the efficiency of water use, increases recycling and reuse of water, or prevents the pollution of water (87).

Why water conservation should be a priority in labs? First of all, there is a wide range of water-using equipment in laboratories and with small steps it is relatively easy to improve efficiency which will possess excellent savings potential. Financial savings may be achieved through water-efficiency measures, without huge capital outlays. Much of these savings can be immediately realised through minor repairs to existing infrastructure and through staff behaviour, while others may require an initial capital investment that can be recovered within a specified payback period. On the other side, to reduce the amount of water used in laboratories will ensure that humankind will have safe, secure supplies for the future. Furthermore, conserving water also conserves energy. By increasing efficiency through water conservation and recycling practices, lab facilities can further cut energy consumption and thus carbon footprint.

In preparation for developing a water strategy, the issue of water management should be raised at a senior management level and support secured. Senior management should also discuss the possibility of integrating water-efficiency goals into key performance indicators (88).

Although laboratories will never be able to reduce their water consumption to the level of office spaces, it is worth working on efficient conservation strategies and keep the water use as low as possible. Laboratories should not, initially, be too ambitious. They should initially set achievable targets for the introduction of good environmental practices and start with practices that are feasible. This involves the reduction of water consumption (49). All efforts should be seen as a process of continuing improvement

Targets for sustainable practices in clinical laboratories regarding managing water consumption may be defined as follows (9,51,58,89):

- Assessing the water quality needed for each laboratory process.
- Reduction of water consumption in the laboratory's workflow.
- Adoption of a green purchasing policy.
- Improvement of laboratory process equipment (cooling of equipment, rinsing, and flow control).
- Water-efficient and environmentally friendly design of laboratory/hospital buildings-Using LEED (Leadership in Energy and Environmental Design) on laboratory projects (water efficiency as one of seven categories).
- Use of alternative water sources when and where possible (air-conditioning condensate recovery and rainwater harvesting).
- Collaboration between hospital buildings and laboratory networks for resource sharing.

6.2. HOW CAN LABORATORIES REDUCE WATER CONSUMPTION?

6.2.1. METER/MONITOR WATER CONSUMPTION (53,58,61,90–95)

- Tap water

  Always turn off the tap when not in use.

  Use electronic faucets that turn-off automatically when not required.

  Post signage with reminders to turn off the water.

- Use timers

  Install or use timers on critical or continuous water uses.

- Install low-flow aerators

Install low-flow aerators on lab faucets. Low-flow aerators are small, very cheap devices that simply screw onto the faucet, reduce the flow to 1.5 to 0.5 gallons/minute and mix the stream with air, reducing water waste without disturbing water usage productivity. Labs without aerators or with outdated aerators are suggested to have new aerators installed.

- Install flow restrictors

  A number of fixtures (for example, hand basins, sinks and wash troughs) have unregulated water flows that may lead to higher use. Installing flow restrictors with balanced pressure is generally a cost-effective way to reduce water use without affecting functional requirements.

- Install sink aerators

  In laboratory, this means removing any tubing and barb attachments from faucets, screwing in a sink aerator, and replacing the tubing (used to fill containers and eliminate splash), and securing it with a clamp. The equipment is very cheap, installation can be completed in five minutes, and the result is up to 50% reduction in water usage.

- **Install water misers** for reducing water consumption (installing water misers on autoclaves and sterilizers reduce water consumption by 50 %)
- **Conduct a water audit** (identifies uses, usage patterns, and quantify potential water-saving opportunities)
- **Install data-logging water meters** on incoming water enables ongoing monitoring. This helps to identify trends, usage patterns and leaks. Data-logging meters at the boundary are useful because out-of-hours data (when water use is expected to be very low) becomes readily available. The data loggers are usually sourced from your water retailer.
- **Install sub-metering-**Metering of separate buildings and key processes enables usage and trends to be monitored throughout the site. The use of meters that are connected to a building management system (BMS) enables easy data collection.
- **Maintenance and checking the plumbing system regularly** (in accordance with existing laboratory standard operating procedures)
- **Check for faucet leaks** and report them promptly to the facilities department or your building manager for immediate repair. Leaky faucets that drip once per second can waste 3,000 gallons of water per year.
- **Check for leaks on autoclaves, ice machines, and water-cooled equipment** (anywhere you have a line that constantly maintains water) and report them promptly to the facilities department or your building manager for immediate repair.

6.2.2. EQUIPMENT AND INSTRUMENTATION

Equipment and instrumentation selection (9)

- In pre-purchase evaluation of equipment/instruments, water consumption assessment should be introduced. Priority should be given to low water consumption items, to manufacturers who use environmentally friendly manufacturing processes and/or to those who have ISO certification for good environmental practices, supporting in that way the laboratory's commitment to the environment.
- If possible, include a green element to procurement. Sustainable procurement, sometimes called Environmentally Preferred Purchasing, can play a big role in achieving a hospital's sustainability strategies.
- Changing an automated laboratory system offers the opportunity to make significant enhancements to good environmental practices, for patients and the laboratory (reduction of blood tubes collected from each patient, reduces material costs, decreased water usage and waste).

6.2.3. LABORATORY COOLING TOWERS (89)

Cooling towers, which are part of many laboratory buildings, might represent the largest single opportunity for greater water efficiency:

- Increasing the recycle rate of the tower reduces the consumption of make-up water
- Better monitoring and management of the water chemistry
- Using conductivity and flow meters
- Design for greater water efficiency using plume abatement or a hybrid tower design
- Utilise side-stream filtration, sunlight covers, alternative water treatment systems, and automated chemical feed systems
- Savings on water and sewer costs, savings also result from having to purchase fewer chemicals to treat the water.

6.2.4. LABORATORY PROCESS EQUIPMENT

Equipment Cooling, equipment used in rinsing, and flow control (53,89–91)

In addition, water efficiency can take place in the cooling of equipment, rinsing, and flow control:

- Reduce/eliminate single-pass cooling (typically consumes more water than any other cooling method in laboratories). The best way to combat the water waste associated with single-pass cooling is to use a recirculating process or cooling loop through a cold-water bath. Eliminating this from your workflow can save hundreds of thousands of gallons of water each year and prevent the risk of flooding. If possible, move your process to a cooler room.
- Utilise small, packaged chillers for greater water control and reduced water usage

- Counter-current rinsing to use the cleanest water only for the final or last stages of a rinse operation, and batch processing
- Using a control or solenoid valve to allow water to flow only when the unit is being used

6.2.5. NON-SPECIALISED EQUIPMENT

Non-specialised equipment such as laboratory water treatment, sterilization, photographic, X-ray, and vacuum systems can also benefit from implementing water efficiency processes:

6.2.5.1. WATER-TREATMENT EQUIPMENT (53,86,91,92,96–98)

- Use water purification only when necessary and match the process to the actual quality of water required.
- Rinse bulky glassware or equipment with regular tap water before utilizing deionised water for the last stage of rinsing.
- Determine the quality of water required in each application; use the lowest appropriate level of quality to guide the system design (FEMP 2004).

Limit the use of deionised water. The College of American Pathologists (CAP) recommends that all water used for any application in laboratory testing meet the Clinical Laboratory Reagent Water (CLRW) standard specified by the Clinical Laboratory Standards Institute (CLSI) as a minimum. In addition, instrument feed water must meet the instrument manufacturer's specifications – which may be more rigorous than CLRW standards – to ensure accurate and reproducible results.

- Choose a filtration process that matches the laboratory's requirements for high-quality water, including the total volume and the rate at which it will be needed, so that the system can be properly designed and sized.

The main treatment process is usually a reverse osmosis membrane, which removes up to 99 percent of water impurities. Other supporting technologies include specific modules and cartridges, ultraviolet lamps, and ultrafiltration to further ensure that the CLRW water quality is consistently and reliably met, while minimizing operating costs and the need for user intervention.

- Consider using one of the proprietary systems for improving system efficiency; using the model that removes excess chemicals from the film reduce chemical carryover by 95% and reduce the amount of water needed in the wash cycle.

6.2.5.2. DISINFECTION/STERILIZATION SYSTEMS (89,91,92,98)

- Focus on water consumption for autoclaves and sterilizers which can consume large amounts of water
- Run at full capacity
- Set them to stand-by mode or shut off units that are not in use or install an automatic shut-off feature if it does not interfere with the unit's normal operation.
- Choose right-size autoclave for the number of cycles you run
- Consider water-efficiency when purchasing autoclaves
- Adjust flow rates to the minimum ones recommended by the manufacturer, and review and readjust them periodically.
- Install water-saving devices on existing autoclaves whenever possible

Consider purchasing a water conservation retrofit kit; many are now available for older units. They reduce water use by either controlling the flow of tempering water (save about 2900 gallons per day) or by replacing the venturi mechanism for drawing a vacuum (save approximately 90 gallons per cycle).

- Newer models are available that use less water (and energy)

6.2.5.3. PHOTOGRAPHIC AND X-RAY SYSTEMS (9)

- Move to digital X-ray and photography, and computerized printing to eliminate chemical and water needs for printing

6.2.5.4. VACUUM SYSTEM (9,92,97,98)

- Eliminate vacuum aspirators. Use a vacuum pump instead. This can save about about 238 gallons (900 litres) of water per hour of use.
- Install a laboratory vacuum system or to employ small electric vacuum pumps to create the pressure differentials necessary for vacuum applications
- Always turn OFF vacuum pumps when not in use. Leaving vacuum pumps running continuously leads to pump failure and excess water use for cooling.

6.2.5.5. WATER BATHS (54,95,96,98)

- When working with a water bath, always cover it. This allows you to maintain the required temperature using less energy and reduces evaporation.
- Use melted ice for non-sterile procedures like filling water baths.
- Use a waterless "water bath" or a bead bath as an alternative to a traditional water bath to reduce water use, energy use, reducing risk of microbial growth and sample contamination.

6.2.5.6. ICEMAKERS (98)

- Use air-cooled instead of water-cooled (open loop) icemakers, or tie into a year-round process cooling loop if one is available

- Specify ENERGY STAR icemakers that use an average of 15% less energy and 10% less water
- Cycle them off at night and on weekends

6.2.5.7. WASHING AND DISHWASHERS (9)

- Consider soaking rather than continuous flushing to conserve water.
- Run dishwasher only when it is fully loaded.
- Use newer dishwashers use less water than older models.
- Use newer, cleaner rinsing detergents.
- Reduce the number of rinse cycles whenever possible and use minimum flow (50).

6.2.5.8. PAPER USE (98–100)

- Buy chlorine free paper
- Recycle and reuse paper
- By purchasing paper with recycled content, water consumption to make the paper is reduced by nearly 60%.
- Reducing and discouraging staff from printing, encourage printing only where necessary.
- Reduction of paper through paper-less environment with the implementation and use of electronic prescription and electronic results transmission
- Stimulate lab – lab informatic exchanges for requests and results transmission
- Integration of laboratory services to electronic medical records and health data hubs.

6.2.6. ALTERNATIVE WATER SOURCES (89)

Laboratory buildings can increase their total water supply using alternative source of water for nonpotable water:

- Recover condensate water, which is relatively free of minerals and other solids.
- Harvest rainwater as another source for nonpotable water use.
- Reclaim wastewater for some nonpotable applications, such as cooling tower make-up.

7. GENERAL ISSUES

7.1. POLICY, EDUCATION AND ADVOCACY

- Institute an environmental policy, provide documentation and a staff training program on environmental issues and best practices.
- Publication of action plans, guidelines, and policy documents regarding sustainable practices.
- Promote audits to evaluate progress before and after sustainable measures.
- Appoint an environmental manager and obtain support from senior management by advocating for corporate responsibility, financial benefits and increased laboratory reputation among customers and the community.
- Set the example through senior members and provide employee feedback.
- Implement control measures to avoid or minimize the release of hazardous substances into the work environment and the number of exposed employees. Train workers in the use of hazardous chemicals, safe work practices and appropriate use of Personal Protective Equipment (PPE).
- Educate and communicate about the environmental policy to the different stakeholders involve at the different phases of the analytical cycle (pre-pre-analytical, pre-analytical, analytical, post-analytical) including both hospital and primary care activities (when relevant).
- Advocacy:

The community in general supports environmental initiatives. Engage groups associated with the clinical laboratory, such as patients, contractors, colleagues, and the government.

7.2. STEWARDSHIP OF RESOURCES

Laboratory testing costs constitute approximately 3% of all clinical costs, with a common strategy to reduce healthcare expenditure being a random reduction of laboratory budgets and unnecessary tests (101). Thus, auditing requests of laboratory tests to identify test redundancy can decrease the number of reagents and hazardous chemicals used. The World Health Organization (WHO) published an Essential in Vitro Diagnostics (IVD) List, which identified 35 test categories of general IVDs that can be used for the diagnosis of several common diseases and 27 test categories of IVDs for the management of HIV infection, tuberculosis, malaria, hepatitis B and C, syphilis, and HPV infection (102).

Reducing unnecessary testing appears as one of the most effective approaches to reduce the carbon footprint of pathology (47).

The implementation advisory groups to educate about the rational use of laboratory tests among hospital and primary care settings. Stewardship to review urgent testing in ambulatory care could be wise as emergency analyses requiring on-call couriers have impact on carbon footprint (48).

Test wisely means also recommend testing for diagnosis and prevention when under-requesting is suspecting and might have healthcare consequences. Example in primary care in Spain can illustrate it (103).

Laboratory resources stewardship means therefore interventions at both sides, over- and under-requesting.

7.3. GREEN PURCHASING

Healthcare represents approximately half of the EU government expenditure, with more than 15 000 hospitals (104). Therefore, clinical laboratories can play a role in shifting supply and demand of chemicals towards green alternatives by adopting a green purchasing policy, which includes the selection and acquisition of products that minimize environmental impacts over their entire life-cycle: use recyclable, recycled, less toxic and locally produced chemicals whenever possible.

The European Commission and several European countries have developed guidance for green public procurement with the inclusion of clear and verifiable environmental criteria for products and services in the procurement process (105).

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