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Review

Advancing green laboratory practices: A review of sustainability in healthcare

Srinidhi Rai[1], Naresh Sriram[1], Priya Alva[1], Asem Ali Ashraf[2], Santhosh Kumar[3], Shyamala Nayak[4]

[1]Department of Biochemistry, Nitte (Deemed to be University), Mangalore, India
[2]Department of Microbiology, Nitte (Deemed to be University), Mangalore, India
[3]Department of Paediatrics, Indiana University School of Medicine, Indianapolis, USA
[4]Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Manipal Karnataka, India

Abstract

As awareness of the environmental impact of healthcare facilities, including laboratories, grows, there is a pressing need to adopt sustainable practices within laboratory medicine. Sustainability is therefore a key goal in the quickly evolving healthcare landscape. This review explores forward steps in green medical laboratory practices and offers perspectives on sustainability in healthcare, specifically within the context of laboratory medicine. The review assesses the environmental footprint of laboratory operations, considering factors such as energy consumption, resource utilization, chemical usage, and waste generation. Technological advancements and educational initiatives aimed at fostering a culture of sustainability are also discussed as essential components of the transition toward greener medical laboratory practices. This review underscores the importance of integrating sustainability principles into laboratory medicine to mitigate environmental impact while ensuring the delivery of high-quality healthcare services for present and future generations.

Keywords: Environmental impact, green lab, sustainability

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In the rapidly changing field of healthcare, sustainability is a key goal. Attention to sustainability is crucial for governments, the general population, and the healthcare system [1]. In 1987, the United Nations released the Brundtland Report, which defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2, 3]. Although healthcare facilities work to maintain and enhance public health, their effects on the environment can have a detrimental effect on the welfare of people and other living things [4]. Sustainability in healthcare has evolved from being primarily environmental to being a comprehensive concept that takes socio-ecological and socio-technical system balance into account [5].

Ironically, the healthcare sector is one of the biggest emitters of greenhouse gases despite its commitment to protecting and enhancing human health. It is critical that healthcare practices embrace sustainability and actively work towards achieving carbon net zero in the face of this worsening global catastrophe.

Green Laboratory Design and Infrastructure

Medical laboratories are essential for diagnostics but pose significant environmental challenges due to their energy-intensive operations. Traditional lab designs prioritize functionality over sustainability, leading to high energy consumption, inefficient space use, and negative environmental impacts. Com-

Address for correspondence: Srinidhi Rai, MD. Department of Biochemistry, Nitte (Deemed to be University), Mangalore, India
Phone: 9591247186 **E-mail:** srinidhirai@nitte.edu.in **ORCID:** 0000-0002-4769-9002

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pared to an office block, a typical laboratory needs three to six times as much energy per unit surface area [6]. This high energy demand increases operating costs and contributes to environmental degradation, including greenhouse gas emissions and waste generation. Poor lab layouts also result in underutilized space and poor indoor air quality, posing health risks. In addition to energy consumption, labs are significant water users and waste producers. Sustainable water conservation measures include acquiring instruments with reduced water usage, installing automatic shut-off valves on sinks, and using adjustable water settings. Prioritizing eco-friendly manufacturers with ISO certification can further enhance sustainability. As healthcare institutions strive to meet rising service demands while reducing their ecological footprint, adopting sustainable design principles in labs is imperative. Sustainable labs offer numerous benefits, including reduced energy consumption and operating costs through optimized space utilization and energy-efficient technologies. Enhanced ventilation and filtration systems improve indoor air quality, creating a healthier work environment. Additionally, sustainable design future-proofs lab infrastructure against evolving regulatory requirements and market dynamics, enhancing organizational resilience.

Passive Energy Systems

Leveraging natural light, passive solar heating, and natural ventilation mitigates energy usage while enhancing occupant comfort, forming a cornerstone of sustainable laboratory design. Natural light reduces the need for artificial lighting by incorporating large windows, skylights, and light wells, creating a more pleasant and productive environment. Passive solar heating maximizes solar heat gain in winter and minimizes it in summer through strategic window placement, shading devices, and thermal mass, reducing reliance on traditional heating systems. Natural ventilation, using operable windows, louvers, and vents, improves air quality and reduces the need for mechanical systems. These passive energy systems not only cut energy consumption but also enhance the overall experience for staff and visitors [7].

The U.S. Environmental Protection Agency (EPA) has criteria for sustainable laboratory design focusing on reducing emissions, improving technology efficiency, and promoting resource management. Adhering to these standards helps laboratories reduce environmental impact while enhancing operational efficiency and cost-effectiveness [8].

Emission Reduction

Sustainable laboratory design and operation aim to minimize emissions of pollutants and greenhouse gases. This can be achieved through the use of energy-efficient equipment, such as low-emission fume hoods and energy-efficient lighting systems. Additionally, laboratories can implement waste reduction and recycling programs to minimize the generation of hazardous waste and reduce emissions associated with waste disposal [9].

Technology Efficiency

The EPA encourages laboratories to adopt energy-efficient technologies that reduce energy consumption and improve overall efficiency. This includes the use of energy-efficient HVAC (Heating, Ventilation, and Air Conditioning) systems, high-efficiency lighting, and energy-efficient laboratory equipment. Laboratories can also implement energy management systems to monitor and optimize energy use, further reducing energy consumption and costs [10].

Prudent Resource Management

Sustainable laboratory design and operation also involve prudent resource management, including the efficient use of water, materials, and chemicals. Laboratories can implement water-saving measures, such as low-flow faucets and water-efficient equipment, to reduce water consumption. Additionally, laboratories can use environmentally friendly materials and chemicals, such as non-toxic cleaning products and recycled materials, to minimize their environmental impact [11].

Load minimization is a critical aspect of sustainable laboratory design and operation. It involves aggregating areas with similar energy demands and minimizing loads to reduce energy consumption and improve air quality within the laboratory. By optimizing the distribution of energy loads and reducing the overall energy demand, laboratories can achieve significant energy savings and create a healthier indoor environment for occupants. One of the key strategies for load minimization is to aggregate areas with similar energy demands. This involves grouping laboratory spaces based on their energy requirements, such as temperature and humidity control, lighting, and equipment usage. By clustering areas with similar energy needs, laboratories can optimize the distribution of energy loads and reduce the overall energy demand. Laboratories can also implement energy management systems to monitor and optimize energy use, further reducing energy consumption and costs [12].

HVAC Systems Optimization

Employing efficient HVAC systems, variable air volume (VAV) ventilation, and low-flow hoods significantly reduces energy consumption and enhances air quality management. Selecting energy-efficient HVAC systems minimizes energy use while providing optimal comfort, leading to substantial savings. VAV systems adjust airflow based on demand, reducing energy consumption and improving indoor air quality. Additionally, low-flow hoods provide necessary ventilation with minimal air conditioning, further reducing energy use and enhancing the working environment [13].

Renewable Energy Integration

Harnessing wind turbines, solar panels, and biomass systems as renewable energy sources is crucial for sustainable laboratory operations. Integrating renewable energy reduces reliance on fossil fuels and lowers carbon footprints. Solar panels, commonly installed on roofs or walls, convert sunlight into electricity for laboratory equipment, lighting, and HVAC systems. Wind turbines, placed on or near laboratory buildings, capture wind energy for similar uses. Biomass systems generate heat and electricity from organic materials like wood chips and agricultural residues, further reducing dependence on grid electricity and fossil fuels [14].

Cost Analysis

Utilizing building simulation technology enables precise cost analysis, ensuring alignment with energy efficiency and financial goals. This technology accurately models the energy performance of laboratory buildings, allowing identification of potential improvements. Detailed cost analysis helps determine the most cost-effective energy efficiency measures, maximizing energy savings. Additionally, building simulation technology predicts long-term energy savings, assessing the financial viability and payback period of these measures. This ensures laboratories achieve a positive return on investment while meeting their energy efficiency objectives.

Design Flexibility

Flexible infrastructure enables seamless integration of emerging technologies and facilitates future upgrades, making it a key aspect of green labs. This design flexibility allows laboratories to adapt to changing needs and incorporate new technologies, ensuring continued efficiency and sustainability. It helps labs stay at the forefront of innovation by easily integrating new technologies and future-proofing their facilities. Additionally, flexible infrastructure simplifies future upgrades, allowing labs to meet new requirements without costly and disruptive renovations, maintaining efficiency and sustainability over time [15].

Comprehensive Commissioning

Third-party commissioning validates laboratory systems, enhancing quality assurance and performance optimization, a critical aspect of green labs. Comprehensive commissioning identifies and addresses deficiencies or inefficiencies through thorough testing and verification. This ensures systems function as intended and meet performance objectives. Additionally, it identifies opportunities for energy savings, recommending measures to enhance efficiency, reduce energy consumption, and lower costs [16].

Rethinking Renovation

Repurposing existing facilities with sustainable systems or renovating buildings to align with eco-friendly practices offers a pragmatic approach to minimizing environmental impact. This is crucial for green labs, allowing them to reduce their carbon footprint and leverage existing infrastructure. Renovating with sustainable features like energy-efficient lighting, HVAC systems, and water-saving fixtures creates more sustainable and comfortable working environments, benefiting both the environment and laboratory staff [11].

Green Procurement Practices

Procuring green lab concept

Implementing green revolution measures in a clinical laboratory involves adopting environmentally sustainable practices to minimize resource consumption, reduce waste, and promote overall eco-friendliness.

Chemical Management

Chemicals play an integral role in our society, contributing to advancements in human health and the extension of life expectancy, particularly within the realms of healthcare and clinical laboratories. Despite their crucial contributions, these substances also pose potential risks to both human health and the environment due to their inherent hazardous nature. While chemicals have undeniably enhanced various aspects of our lives, there is a need for careful consideration and management to mitigate any adverse effects they may pose to health and the environment [17]. The risks associated with chemicals encompass their entire lifecycle, spanning production, transport, use, and disposal. Ensuring the proper and sustainable management of chemicals is of utmost importance. Hazardous chemicals, identified as significant contributors to various health conditions in the European Union (EU), have been linked to ailments such as cancer, neurodevelopmental disorders, reproductive issues, metabolic disorders, cardiovascular diseases, and respiratory disorders. Addressing these risks requires comprehensive measures at every stage of the chemical lifecycle to safeguard both human health and the environment [18]. Typically, population subgroups facing greater vulnerability, such as children from lower socioeconomic backgrounds, are more prone to developing diseases linked to pollution [19]. Moreover, exposure to chemicals, even at low levels, can contribute to enduring health effects. This includes issues like decreased fertility, lower birth weights, and neuropsychiatric conditions in children. Approximately 10–15% of all births exhibit neurobehavioral development disorders, with attention-deficit hyperactivity disorder (ADHD) and autism spectrum disorder presenting a widespread distribution. Addressing these challenges is crucial for promoting the long-term health and well-being of vulnerable populations, particularly children. By embracing green chemistry, there is a concerted effort to evaluate the overall life cycle impact of a particular chemical. This approach aims not only to enhance the efficiency of chemical processes but also to prioritize sustainability, safety, and environmental responsibility throughout the entire life cycle of chemical products [20].

To eliminate or reduce hazardous chemicals effectively, the following actions, as suggested in reference, can be implemented [21]:

1. Eliminate Hazardous Chemicals Whenever Possible:
    - Replace mercury thermometers with safer alternatives.
    - Cease the use of ethidium bromide for gels.
    - Explore and adopt solventless chemical reactions when feasible.

- Utilize computer simulations as substitutes for experimental procedures.

2. Reduce Quantities of Harmful Chemicals, Reagents, and Precursors:
   - Implement more efficient chemical reactions to minimize the overall quantity of hazardous substances.
   - Embrace green chemistry principles to substitute harmful chemicals with less toxic alternatives.
3. Procurement:
   - Prioritize the procurement of chemicals with lower toxicity and environmental impact.
   - Collaborate with suppliers who adhere to sustainable and environmentally friendly practices.
   - Consider life cycle assessments when selecting chemicals to understand their overall impact.

By actively implementing these measures, laboratories can contribute to the reduction of hazardous chemicals, promoting safety, sustainability, and environmental responsibility in their practices.

Equipment Selection

The selection of equipment for a laboratory should prioritize environmentally friendly options to promote sustainability. Laboratory instruments such as fume cupboards, -80°C freezers, autoclaves, and incubators frequently operate around the clock and, on average, consume energy equivalent to or greater than that of a typical single-family house. Efficient freezer management plays a crucial role in reducing energy consumption. This involves regular defrosting, discarding unnecessary samples, and frequent cleaning of filters and condensers to facilitate the dissipation of generated heat. Minimizing the duration of freezer door openings also contributes significantly to energy conservation [22]. A significant measure to reduce energy consumption involves adjusting the freezer temperature from -80°C to -70°C [23]. This modification can result in a decrease in energy usage by 20%–34% while simultaneously improving temperature consistency (±1°C at -70°C compared to ±4.5°C at -80°C). Powering off instruments when not in use can also yield a substantial impact. In a clinical laboratory, for instance, this practice contributes to energy conservation. Finally, it is crucial for laboratories to embrace sustainable procurement practices. This involves establishing an efficient ordering process, implementing proper inventory management to reduce unnecessary transport and CO2e emissions, and actively seeking out more sustainable products.

Education and Training for Sustainable Practices

A circular economy – minimal usage of Earth's resources

Global healthcare waste creation is increasing at an accelerated pace of 2%–3% as healthcare facilities expand to meet demand worldwide [24]. The amount of trash generated by the global healthcare industry is quickly becoming an environmental problem. To reduce this impact, appropriate treatment plans and focused management must be implemented prior to the waste becoming waste. Healthcare settings must implement secure systems that collect, transport, separate, and handle waste before disposing of it. As practitioners of healthcare science, we may take steps to lessen clinical laboratory practice's carbon impact and ultimately assist the healthcare industry in meeting its carbon-zero goals.

According to a 2015 evaluation done by the World Health Organization (WHO), very few nations were found to have adequate waste disposal systems. Outdated technologies, lack of worker skills, and restricted budget allocation were the causes of this shortfall. A clinical laboratory must collaborate and work with all other links in the supply chain, including other departments, organizations, suppliers, and regional education providers, for reuse, repair, and reconditioning to be successful. Reselling resources can result in financial gains, sharing resources lessens the demand for new manufacturing, and repurposing equipment in educational settings not only promotes the circular economy model but also offers practical training possibilities for the workforce of the future.

Advocating Practice: The Carbon Footprint of Travel

When analyzing the travel connected to healthcare that occurs in laboratories, we must take into account travel by the staff, suppliers, patients, and samples. Administrators in laboratories should think about advocating for a decrease in carbon-intensive forms of transportation and implementing practices that can lessen the carbon footprint of delivering samples and resources. Frequent variations in the need for tests can frequently result in urgent "kit" orders, where providers receive several requests for a single supply of goods—often carried out using carbon-intensive methods—from suppliers. Carbon emissions can be reduced by promoting the sharing of kits and consumables among groups in times of need, thereby doing away with the requirement for single-item, long-distance deliveries.

Sample Collection and Processing

The laboratory's carbon footprint will be impacted by the quantity of samples collected, the mode of transportation, the delivery route, and the frequency of collection. It is simple to understand how the laboratory contributes to the plastic waste of healthcare when you take into account the creation, usage, and disposal of sample transport bags. The majority of healthcare laboratories make an unquantifiable contribution. Although the switch to single-use plastics is a major factor in the creation of plastic trash, we can take action to change this behavior. One proposal is to replace single-use sample bags with sample transport boxes. Not only may samples be carried in boxes safely and securely, but moving away from bags also increases sample loss prevention and confidentiality. With just a little initial work, a straightforward modification like a reusable transport box can cut down on the usage of single-use plastics, speed up the process of unbagging samples, and shorten turnaround times [25].

Sustainability in Clinical Laboratories

Phlebotomy practitioners may encounter many challenges, such as mislabeling, sample rejection, and retests. However, we must not overlook the necessity of teaching medical professionals how to reduce the number of unnecessary tests they order. Overall, meaningful carbon savings and environmental advantages can be achieved by lowering the quantity of samples that are carried, processed, and disposed of.

Avoiding Damages

In order to address the climate and public health crises, it is imperative that we, as ethical healthcare practitioners, collaborate, teach, and exchange sustainable methods. Individually, we must integrate the sustainability agenda into our practice both now and in the future and make sure that sustainability practice education permeates every aspect of our work, including professional qualifications, professional development materials, and inductions. Due to its straightforward premise that encourages product reuse, repair, and reconditioning, the circular economy is a workable alternative. However, we must manage the sustainable healthcare supply chain before a circular model can be implemented. Information gathering, supply analysis, dialogue and cooperation with suppliers, evaluation of service providers, and investment from both internal and external sources, as well as the involvement of end users, are all necessary to get there [26]. Numerous studies [27] have demonstrated that pre-analytical errors can lead to an unwarranted carbon footprint; hence, the demand for higher education is pressing.

Point-of-Care Testing and Its Pertinence

Point-of-care testing (POCT) is considered to have a significantly lesser impact than laboratory analysis, frequently due to the fact that fewer staff, sample, and patient transportation requirements apply. Additionally, the method improved the environment since the POCT test would eliminate the requirement for laboratory analysis. However, it is pertinent that essential clinical patient needs and quality control procedures are taken into account while implementing POCT. Sustainability in Quality Improvement (SusQI) is one such project that serves as a solid paradigm for Education for Sustainable Development (ESD) in healthcare professional development. The healthcare version of ESD, known as SusQI, was created by The Centre for Sustainable Healthcare (CSH) [28] and considers four principles of sustainable healthcare [29]: Prevention, patient self-care, lean delivery, and low-carbon alternatives. Healthcare professionals who promote sustainability across many professional groups and disciplines can receive virtual training and help from CSH to integrate these ideas into ESD. Therefore, the foundation for professional sustainability education delivery in higher education and the healthcare industry can be formed by the principles of ESD and SusQI.

Since 2015, the advancement of ESD spearheaded by UNESCO has evolved, and it is now being incorporated into high-quality frameworks for continuing professional development in both global healthcare and education [30]. ESD's overarching goal is to transform society by equipping learners with essential information, skills, values, and attitudes. Healthcare practitioners can learn about ESD abilities by applying the following principles: Thinking (future, systems, and creatively), learning (collaborative and participatory), and critical reflection. Future thinking is the process of analyzing social, environmental, and economic goals as well as the effects of inactivity through peer debate. Systems thinking involves applying case studies that are connected to students' current work to help them comprehend carbon measurement, circular economy modeling, and the teamwork needed to bring about change. Using team-based learning techniques, reflective practice, didactic instruction, and critical analysis of research with supporting data, critical reflection is accomplished. Peer and experiential learning that takes action research in the workplace into account is known as participatory learning. Using creative thinking and project-based learning to promote change, problem-based learning is connected to local Quality Improvement standards. Collaborative learning includes interprofessional collaboration, local and guest expert contributions, and collaborative learning methodologies. As a healthcare laboratory expert begins to think about sustainability, knowledge is necessary for an accepted impact measurement. The laboratory professional must gain knowledge of social impact measurement, circular economy modeling, and carbon measurement. To obtain maximum good social results, the proposed modification concept must take into account both the positive and negative social repercussions of the current system. Single-use plastic products are extensively used from a quality and safety as well as health standpoint. In addition, there is no avoiding the sector's high energy usage. Through ESD, students should be able to make decisions and take actions that will help the economy and the environment. Education providers acknowledge the importance of ESD in providing high-quality instruction. Therefore, it is essential to instill ESD as a core skill in both present and upcoming graduates as well as practicing professionals. The "triple bottom line" strategy is incorporated into ESD initiatives, which enables the student to use social, economic, and environmental factors to strike a balance for sustainable development [31].

Utilization of SusQI for Laboratory Professional ESD

Any healthcare professional group can readily implement SusQI as a method [32], and any part of the patient pathway, including laboratory diagnoses, can incorporate social and environmental predicaments. Sustainable and green professional practice can be integrated into the laboratory by applying SusQI principles to healthcare laboratory scenarios and promoting problem-solving on how these can be addressed. Interprofessional collaboration also has the added benefit of increasing the profession's visibility.

Conclusion

In conclusion, the imperative for sustainable practices in healthcare, particularly in laboratory medicine, cannot be overstated. The traditional approach to laboratory design and operation is inefficient and environmentally detrimental. However, by embracing green practices and implementing sustainable design principles, laboratories can significantly reduce their ecological footprint while enhancing operational efficiency and cost-effectiveness.

Key strategies such as emission reduction, technology efficiency, prudent resource management, passive energy systems, HVAC systems optimization, renewable energy integration, cost analysis, design flexibility, comprehensive commissioning, and rethinking renovation all contribute to the overarching goal of creating a more sustainable healthcare infrastructure.

The transition to sustainable laboratory practices is not only a moral imperative to protect our planet for future generations but also a strategic necessity to ensure the long-term viability of healthcare systems worldwide. By prioritizing sustainability, laboratories can contribute to mitigating climate change and foster healthier and more productive work environments for laboratory staff and patients alike.

Advancing green medical laboratory practices is not merely an option but a responsibility that healthcare institutions must embrace to safeguard public health, protect the environment, and pave the way for a more sustainable future.

In essence, the integration of sustainable practices within clinical laboratories is paramount for mitigating environmental impact, promoting resource conservation, and ensuring the long-term viability of healthcare systems. Through collaboration and innovation, laboratories can lead the way towards a healthier and more environmentally conscious future.

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References

1. Molero A, Calabrò M, Vignes M, Gouget B, Gruson D. Sustainability in healthcare: Perspectives and reflections regarding laboratory medicine. Ann Lab Med 2021;41:139–44. [CrossRef]
2. Biason KM, Dahl P. Strategic steps to sustainability in healthcare - Sustainable Operations. Available at: https://healthcarefacilitiestoday.com/posts/Strategic-steps-to-sustainability-in-healthcare--13629. Accessed Aug 20, 2024.
3. Marimuthu M, Paulose H. Emergence of sustainability-based approaches in healthcare: Expanding research and practice. Procedia Soc Behav Sci 2016;224:554–61. [CrossRef]
4. Buffoli M, Capolongo S, Bottero M, Cavagliato E, Speranza S, Volpatti L. Sustainable healthcare: How to assess and improve healthcare structures' sustainability. Ann Ig 2013;25:411–8.
5. Faggini M, Cosimato S, Nota FD, Nota G. Pursuing sustainability for healthcare through digital platforms. Sustain Times 2019;11:1–15. [CrossRef]
6. Lopez JB, Jackson D, Gammie A, Badrick T. Reducing the environmental impact of clinical laboratories. Clin Biochem Rev 2017;38:3–11.
7. Gammie AJ, Lopez JB, Scott S. Imperative: Reducing the environmental impact of clinical laboratories. Clin Chem Lab Med 2023;61:634–8. [CrossRef]
8. National Research Council. Laboratory Design, Construction, and Renovation: Participants, Process, and Product. Washington DC: Natl Academies Press; 2000.
9. Lopez JB, Badrick T; ad hoc IFCC Panel on the Environmental Responsibility of Clinical Laboratories; APFCB Laboratory Management Committee. Proposals for the mitigation of the environmental impact of clinical laboratories. Clin Chem Lab Med 2012;50:1559–64. [CrossRef]
10. Rampi V, Bisazza O. The EU green deal: The challenge of greening medical technologies. Clin Chem Lab Med 2023;61:651–3. [CrossRef]
11. National Research Council (US) Committee on Prudent Practices in the Laboratory. Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards: Updated Version. Washington DC: Natl Academies Press; 2011.
12. McAlister S, Barratt AL, Bell KJ, McGain F. The carbon footprint of pathology testing. Med J Aust 2020;212:377–82. [CrossRef]
13. Meagan Fitzpatrick. UV Lights in Biosafety Cabinets. Office of Environmental Health and Safety. Available at: https://ehs.princeton.edu/laboratory-research/biological-safety/biological-safety-cabinets/uv-lights-biosafety-cabinets. Accessed Aug 20, 2024.
14. National Renewable Energy Laboratory (NREL). Laboratories for the 21st Century: An Introduction to Low-Energy Design. 2008. Available at: https://www.nrel.gov/docs/fy08osti/29413.pdf. Accessed Aug 20, 2024.
15. Hackman S, Durham J. Emerging practices in clinical laboratory design: It's time to rethink the clinical laboratory from the ground up. Today's Clinical Lab. Available at: https://www.clinicallab.com/emerging-practices-in-clinical-laboratory-design-341. Accessed Aug 20, 2024.

16. Ross J, Penesis J, Badrick T. Improving laboratory economic and environmental performance by the implementation of an environmental management system. Accred Qual Assur 2019;24:319–27. [CrossRef]
17. Ozben T, Fragão-Marques M. Chemical strategies for sustainable medical laboratories. Clin Chem Lab Med 2022;61:642–50. [CrossRef]
18. Giovanni C, Marques FL, Günther WM. Laboratory chemical waste: Hazard classification by GHS and transport risk. Rev Saude Publica 2021;55:102. [CrossRef]
19. Carpintero A. Guidelines for National Waste Management Strategies: Moving from Challenges to Opportunities. United Nations Environment Programme (UNEP), United Nations Institute for Training and Research (UNITAR), Inter-Organisation for the Sound Management of Chemicals (IOMC): Osaka, Japan; 2013.
20. Goldenman G. Study for the strategy for a non-toxic environment of the 7th Environment Action. Available at: https://cswab.org/wp-content/uploads/2018/03/European-Strategy-for-Persistent-Chemicals-2017-.pdf. Accessed Aug 20, 2024.
21. Scott S, Ozben T, Rampi V, Gruson D, Gammie A, Lopez J, et al. EFLM Guidelines for green and sustainable medical laboratories. Available at: https://www.eflm.eu/upload/docs/EFLM-GREEN-LAB-BOOKLET.pdf. Accessed Aug 20, 2024.
22. Hafer M. Quantity and electricity consumption of plug load equipment on a university campus. Energy Efficiency 2017;10:1013–39. [CrossRef]
23. Pali-Schöll I, Hermuth-Kleinschmidt K, Dramburg S, Agache I, Mayerhofer H, Jensen-Jarolim E, et al. An EAACI review: Go green in health care and research. Practical suggestions for sustainability in clinical practice, laboratories, and scientific meetings. Allergy 2023;78:2606–22. [CrossRef]
24. Ranjbari M, Shams Esfandabadi Z, Shevchenko T, Chassagnon-Haned N, Peng W, Tabatabaei M, et al. Mapping healthcare waste management research: Past evolution, current challenges, and future perspectives towards a circular economy transition. J Hazard Mater 2022;422:126724. [CrossRef]
25. Sheri Scott. Laboratory Sustainability: The Need for Green. Available at: https://thepathologist.com/inside-the-lab/lab-sustainability-the-need-for-green. Accessed 20 Aug, 2024.
26. Daú G, Scavarda A, Scavarda LF, Portugal VJT. The Healthcare Sustainable Supply Chain 4.0: The circular economy transition conceptual framework with the corporate social responsibility mirror. Sustainability 2019;11:3259. [CrossRef]
27. Alcantara JC, Alharbi B, Almotairi Y, Alam MJ, Muddathir ARM, Alshaghdali K. Analysis of preanalytical errors in a clinical chemistry laboratory: A 2-year study. Medicine Baltimore 2022;101(27):e29853. [CrossRef]
28. Marsden O, Clery P, D'Arch Smith S, Leedham-Green K. Sustainability in quality improvement (SusQI): Challenges and strategies for translating undergraduate learning into clinical practice. BMC Med Educ 2021;21:1. [CrossRef]
29. Stancliffe R, Bansal A, Sowman G, Mortimer F. Towards net zero healthcare. BMJ 2022;379:e066699. [CrossRef]
30. Beaudoin F, Brundiers K. AASHE. A guide for applied sustainability learning projects: Advancing sustainability outcomes on campus and in the community. Available at: https://static.sustainability.asu.edu/docs/reports/a-guide-for-applied-sustainability-learning-projects-2017.pdf. Accessed Aug 20, 2024.
31. Scott S. Embedding education into clinical laboratory professional training to foster sustainable development and greener practice. Clin Chem Lab Med 2022;61:638–41. [CrossRef]
32. Spooner R, Stanford V, Parslow-Williams S, Mortimer F, Leedham-Green K. Concrete ways we can make a difference: A multi-centre, multi-professional evaluation of sustainability in quality improvement education. Med Teach 2022;44:1116–24. [CrossRef]