Redefining sustainability in the modern laboratory

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Introduction: The urgency and opportunity for sustainability

Sustainability has rapidly become a central focus in bioprocessing and laboratory environments, shaping everything from day-to-day operations to long-term strategic planning across the life sciences sector. This evolution is fuelled by increasing environmental awareness, shifting regulatory landscapes and a growing commitment to responsible innovation throughout the industry. However, the conversation has progressed beyond debating the necessity of sustainable practices. Laboratories are now challenged to identify effective ways to embed sustainability into their operations, while maintaining the high standards of performance and reliability that scientific progress demands.

Sustainable consumables: From concept to reality

The journey toward sustainable laboratory operations begins with a critical examination of consumables, which can contribute significantly to a lab's environmental footprint. For decades, consumables such as pipettes, culture vessels and bioreactor bags have been developed from fossil-fuel-derived polymers and have been praised for their overall strength and durability. However, their inability to break down naturally poses a growing, global environmental challenge. As the scientific community seeks to reduce its overall environmental impact, finding alternatives to fossil-based plastics has become a primary focus for many labs. In fact, studies show that the average laboratory uses 10 times more energy than offices, use 4 times more water than offices and even generate 5.5 million metric tons of plastic waste a year [1].

Recent advancements in plant-based polymers have opened the door to new, more sustainable possibilities and have already begun to generate significant interest among lab leaders. Derived from renewable sources, these materials are engineered to match the chemical and mechanical properties of conventional plastics, helping ensure seamless adoption without requiring changes to already established workflows. However, achieving true equivalence between plant-based and fossil-fuel-derived polymers requires rigorous and extensive data collection and validation. Nonetheless, with the right production techniques, plant-based polymers can be indistinguishable from their fossil fuel counterparts. This removes a significant barrier for labs considering the switch to more sustainable options, eliminating concerns about potential changes across the workflow [2].

An example of the shift from fossil fuel-derived materials to biobased alternatives can be seen in the development of biobased films for single-use bioprocessing containers. A significant effort has gone into engineering plant-based films that are integral to the bioprocessing workflow – films that must reliably withstand chemical exposure, sterilisation and mechanical stresses.

This evolution demonstrates how sustainability can be seamlessly integrated into essential laboratory operations, allowing for an environmental footprint reduction in critical bioprocessing applications while maintaining the performance and reliability standards the life science industry demands.

Overcoming challenges: Consistency and the forever chemicals dilemma

The adoption of plant-based materials brings important challenges, particularly when it comes to ensuring batch-to-batch consistency, which is essential in the production of biologics and therapeutics. Achieving this level of uniformity requires laboratories and suppliers to look upstream in the supply chain. Careful sourcing and meticulous refining of plant oils, followed by their conversion into monomers and high-quality polymers through established chemical processes, are crucial steps. By exercising greater control and fostering close collaboration at every stage, it is possible to produce plant-derived polymers that match the consistency and reliability of traditional fossil-based materials. This approach allows laboratories to meet the stringent demands of bioprocessing and research applications without disrupting validated protocols or established workflows.

At the same time, the industry is grappling with the challenge of 'forever chemicals', particularly persistent fluoropolymers, which have long been valued for their outstanding chemical resistance and thermal stability. However, these materials are now recognised for their environmental persistence and the difficulties they pose in terms of safe disposal and degradation. Increasing regulatory scrutiny and growing awareness of their impact has accelerated the drive to find alternatives. Current research is focused on creating new high-performance polymers from sustainable sources that can withstand the demanding conditions in laboratory and bioproduction settings [3]. The goal is to deliver materials that provide comparable durability and resistance while significantly lowering environmental impact, enabling laboratories to achieve both their operational and sustainability objectives.

Single-use technologies: Driving flexibility and scalability in sustainable labs

Single-use technologies have emerged as a defining innovation in today's laboratory and bioprocessing operations, offering a blend of flexibility, scalability and sustainability that exceeds traditional fixed and stainless-steel systems. These single-use technologies allow laboratories and biomanufacturers to adapt quickly to changing process needs, scale production up or down efficiently and reduce the risk of cross-contamination, all while supporting a more sustainable lab environment.

One of the key sustainability benefits of single-use technologies stems from their ability to minimise cross-contamination and reduce the need for intensive cleaning protocols. By replacing reusable components with sterile, ready-to-use alternatives, single-use systems dramatically decrease water and chemical usage associated with cleaning and sterilisation.

Life cycle assessment (LCA) studies have quantified the environmental advantages of single-use systems, especially in bioprocessing applications such as monoclonal antibody production at commercial scales. These studies, ranging in process volumes from 100 L up to 2,000 L, have demonstrated that single-use systems result in lower water and energy consumption compared to conventional stainless-steel workflows. For example, one LCA found that producing monoclonal antibodies at a 2,000 L scale with single-use systems reduced water use by 87% and energy use by 29% compared to fixed systems. These reductions are primarily due to the elimination of the intensive cleaning and sterilisation processes which are required by fixed, stainless-steel equipment.

The environmental benefits extend to greenhouse gas emissions as well. Studies have also shown how single-use technology can lower the global warming potential of a typical process by 25%, a substantial contribution to reducing the carbon footprint of bioprocessing facilities [4]. In practical terms, switching to single-use systems for a single 2,000 L monoclonal antibody process can save as much as 300,000 litres (about 80,000 gallons) of water, which equates to 16,000 5-gallon water cooler bottles or more than the average annual water usage for two people.

Ultimately, single-use technologies exemplify how advances in design and materials can deliver on both sustainability and performance. By reducing resource consumption, supporting flexible and scalable operations and enabling rapid adoption of more sustainable materials, single-use systems help laboratories and bioprocessing facilities meet their operational goals while supporting a lower environmental footprint, making them a win for both labs and the health of the planet.

The role of automation, analytics and collaboration

One of the most transformative enablers of sustainability in laboratory environments is the integration of automation, advanced analytics and Process Analytical Technology (PAT). Automation has been proven to help reduce manual intervention, decrease the likelihood of human error and enable precise control over complex processes. PAT in particular provides real-time monitoring and control of critical quality attributes during laboratory and bioprocessing operations. This real-time insight allows laboratories to detect even the slightest deviations in process variables, ensuring that workflows remain consistent and efficient as more sustainable materials or methods are introduced.

The combination of PAT with automation is especially valuable when validating the performance of new sustainable materials. Automated systems, equipped with advanced sensors and PAT tools, can continuously monitor a multitude of factors during each process. This data-rich environment enables rapid assessment of how plant-based polymers or other novel materials perform relative to established benchmarks, reducing the time and resources required for validation. Advanced analytics, powered by artificial intelligence and machine learning, further enhances this capability by processing large volumes of data, identifying patterns and predicting outcomes. These technologies empower laboratories to make informed, data-driven decisions and accelerate the adoption of sustainable practices and materials.

Additionally, predictive modelling tools that leverage data from PAT and automation platforms allow labs to assess the potential impact of changes before implementation, further reducing risk and facilitating smoother transitions. Together, this helps increase confidence in moving toward more sustainable options and also supports continuous process improvement and operational excellence.

The advancement of sustainability in laboratories is not possible alone. True progress in sustainability requires collaboration across the entire ecosystem – from suppliers and manufacturers to researchers, academia and regulatory bodies. Knowledge sharing is a vital component of this collaborative effort, and by pooling expertise and data, the industry can more rapidly accelerate innovation [5].

Cross-function collaboration has the potential to lead significant industry-wide changes. Early adopters of sustainable practices have helped pave the way for further implementation, demonstrating through rigorous data and practical experience that plant-based consumables and other innovations can deliver performance on par with, or even superior to, traditional options. Their success has lowered barriers to adoption for others, creating a positive cycle where each new implementation builds confidence and momentum. As more organisations foster this way of collaborative thinking, the adoption of sustainable materials and processes will further accelerate, driving advancement and making sustainability not just an aspiration, but an expectation.

Looking Ahead: Making Sustainability the New Standard

Looking ahead, sustainable laboratory innovation is highly encouraging. Advances in workflow optimisation, digital technologies and material science are providing laboratories with tools that enhance both scientific outcomes and environmental responsibility. Integrating sustainable materials, refining operational practices and upgrading laboratory infrastructure now offer strategic advantages, including improved resilience and adaptability in a rapidly changing industry landscape.

Laboratories that take a proactive approach to sustainable practices will be well-equipped to navigate evolving regulations, meet growing expectations from stakeholders and address potential vulnerabilities in global supply chains. This transformation is driven by collaboration, rigorous data analysis and a willingness to embrace new methodologies, all of which underscore scientific advancement.

Today, laboratories have an important opportunity to set new standards for environmental and social responsibility throughout the scientific community. By committing to sustainable solutions and fostering an environment of shared learning and continuous improvement, laboratories can ensure the ongoing integrity and impact of their research. Just as importantly, they contribute to global efforts to build a healthier and cleaner future. Through leadership in sustainability, laboratories can help define the next era of scientific progress – one that benefits both society and the environment for future generations.

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