Guide

PENDOTECH
Leading Process Analytics

Advancing Sustainability
In Biopharmaceutical Manufacturing

The biopharmaceutical industry is encountering major environmental challenges, largely because of its energy-demanding operations, resource-intensive supply chains, and dependence on chemicals. Addressing these issues requires innovative solutions that balance sustainability with productivity. By integrating advanced single-use technologies, the industry can improve resource efficiency, shorten development timelines, and reduce its environmental impact.

Introduction

Sustainable development is essential in the biopharma industry due to its significant environmental footprint, surpassing even that of the automotive sector (1). This substantial impact results from energy-intensive manufacturing processes, resource-heavy global supply chains, extensive chemical use, and challenges in pharmaceutical waste disposal; all of which contribute to greenhouse gas emissions, pollution, and resource depletion.

Embracing sustainable practices not only mitigates environmental impacts but also enhances operational efficiency by conserving energy and water, while reducing waste disposal costs. Furthermore, companies that prioritize sustainability tend to drive innovation and growth, while attracting customers through their commitment to environmental responsibility.

The Role of Single-Use Technologies

Single-use technologies (SUTs) are key to achieving the United Nations' Sustainable Development Goals 2030 by enabling rapid drug and therapy development, as demonstrated during the COVID pandemic. They improve reproducibility, safety, flexibility, and time efficiency while requiring lower capital investment, driving sustainable innovation in biopharmaceutical development (2). By leveraging established sterilization methods from the medical device industry, SUTs support sustainability through proven, efficient techniques. Process intensification has allowed biopharmaceutical manufacturers to scale down operations while increasing productivity; for example, a 2,000 L single-use system can now produce more protein than a traditional 20,000 L stainless steel system. Ultimately, focusing on sustainability helps biopharma companies fulfill their corporate responsibility and build a resilient, future-ready industry (3).

METTLER TOLEDO

Sustainable Bioproduction Innovations

Single-use systems offer several advantages, including simplified cleaning, agile production, cost-effective manufacturing, and improved productivity through resource conservation. By eliminating the cleaning validation and intensive sterilization processes required for stainless steel, pre-sterilized single-use equipment substantially reduces water, steam, and energy consumption. The flexibility of these systems enables rapid switching between batches and products, fostering innovation and responsiveness to healthcare demands. Lower infrastructure, utility, and cleaning expenses make production more cost-effective and scalable, benefiting smaller facilities. Compared to stainless steel systems, SUTs reduce energy, raw material, and labor costs while shortening cleaning and validation times from days to hours, thereby enhancing productivity and sustainability (4,5).

The bioproduction market has experienced significant growth in single-use technologies in recent years, driven by their flexibility, scalability, speed, and lower costs compared with traditional stainless steel manufacturing. Key drivers include reducing contamination risks and eliminating clean-in-place (CIP) and steam-in-place (SIP) requirements, enabling faster equipment changeovers and improving operational efficiency. This shift supports sustainability by decreasing water use, energy consumption, and waste generation (6,7).

Water Usage

Water usage in single-use systems can be up to 85% lower than in stainless steel plants, primarily because disposables do not require CIP/SIP treatment. Cleaning stainless steel equipment is often the largest water consumer in pharmaceutical facilities, accounting for 50–70% of total water use, and it generates wastewater that requires energy-intensive neutralization and treatment. Additionally, the chemicals used in these processes contribute to the overall environmental footprint (7).

Energy Consumption

Energy consumption in life sciences manufacturing is primarily divided between energy used to produce consumable utilities (such as purified water and clean steam) and energy used to generate utilities for manufacturing and building operations (such as plant steam and chilled water). Single-use systems significantly reduce energy demands by eliminating the need for purified water and steam for CIP and SIP processes, avoiding over 98% of these energy uses compared to stainless steel systems. The remaining energy requirement is mainly for gamma irradiation sterilization of disposables and production of the single-use system parts. Eliminating the need to generate purified water also reduces the size and energy requirements of on-site water purification systems.

One of the greatest energy-saving opportunities lies in reducing cleanroom requirements through closed processing. A life-cycle assessment of a 2,000 L single-use biologics facility found that electricity consumption for cleanroom utilities accounts for the largest environmental impact. Process closure lowers air-quality demands, reducing building size, energy for air-handling, and capital costs for air qualification and monitoring. Both stainless steel and single-use systems can achieve process closure, but single-use technologies offer greater flexibility in doing so with minimal infrastructure changes (7).

Waste Generation

Bioprocessing generates a large amount of plastic waste, which is primarily managed through incineration, waste-to-energy recovery, and previously, landfilling. However, due to contamination concerns, solid unprocessed waste (SUT waste) is no longer disposed of in landfills and is instead commonly incinerated (7).

For hazardous materials that cannot be treated by shredding and steam sterilization, alternative methods such as chemical treatment or gamma irradiation are available. However, they may involve higher costs or limited commercial readiness. There is a significant opportunity to collaborate with recyclers to explore alternative end-of-life solutions. Considering the similar issues faced in managing healthcare plastic waste, the biopharmaceutical manufacturing sector could collaborate with or learn from the healthcare industry to develop more effective recycling approaches (8,9,10).

Although single-use technologies reduce water and energy consumption during manufacturing, they generate more solid waste than stainless steel systems. Addressing this trade-off through circular economy initiatives is essential for the long-term sustainability of the industry.

Our Commitment to Sustainability

METTLER TOLEDO Pendotech has always been dedicated to helping companies boost process efficiency, minimize unnecessary consumption of raw materials and energy, and reduce the risks of increased environmental impact. These risks are associated with high costs resulting from poor product quality caused by inadequate process control. This commitment aligns closely with the biopharma industry's growing emphasis on sustainable development, which is critical given its substantial environmental footprint. By adopting sustainable practices—such as leveraging single-use technologies—companies can not only lessen their ecological impact but also enhance operational efficiency, reduce regulatory risks, and foster innovation and growth. Pendotech's focus on optimized process control supports broader sustainability goals, enabling biopharma companies to build more resilient, efficient, and environmentally responsible operations.

Preventing Batch Waste

Aligned with the FDA's PAT Initiative, the adoption of single-use process analytical technology (PAT)—including disposable real-time monitoring devices—is rapidly increasing to ensure "Quality by Design" in biomanufacturing. Single-use sensors monitor critical parameters such as temperature, pH, dissolved oxygen (DO), and biomass in real time. Their disposability eliminates the need for sterilization, reduces contamination risks, lowers operator exposure to hazardous substances, and provides immediate process feedback. METTLER TOLEDO Pendotech's sensors provide precise measurements of pressure, conductivity, temperature, pH, and UV absorbance, optimizing productivity and yield while preventing costly batch failures. By maintaining consistent process conditions, these sensors protect valuable resources such as purified water, energy, and media, thereby reducing wastage of water and unnecessary energy consumption (11).

Conserving Water

Single-use technologies offer substantial water savings across the bioprocessing lifecycle—from buffer and media preparation through filling and shipment—and are suitable for scales ranging from laboratory research to full production. Scalable and compatible with diverse high-performance bioprocessing equipment, SUTs, as mentioned above, eliminate the need for CIP and SIP operations, significantly reducing water consumption as well as setup, maintenance, and validation times. Economically, this translates into lower capital expenditures and labor costs. Strategically, SUTs accelerate time-to-market and reduce development risks, fostering more agile, flexible, and cost-effective biopharmaceutical manufacturing (12).

Saving Energy

Accurate thermal monitoring through our temperature sensors optimizes heating and cooling cycles, preventing unnecessary energy consumption. This precise control reduces the carbon footprint associated with maintaining ideal bioprocessing conditions and supports energy-efficient manufacturing practices (12).

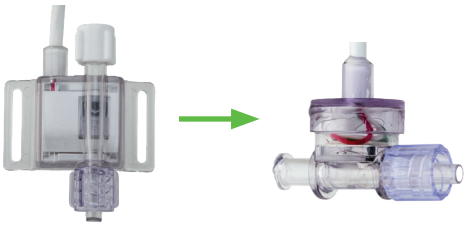
Eliminating Plastic Waste

By enabling real-time, in-line monitoring of critical process parameters directly within the manufacturing stream, Pendotech sensors eliminate the need for off-line sample collection and the associated disposable containers. This significantly reduces secondary plastic waste and contamination risks. Such an approach supports continuous process control and aligns with the PAT framework, promoting enhanced manufacturing quality and operational efficiency (13).

Product Enhancements

METTLER TOLEDO Pendotech has implemented several sustainability initiatives to minimize our environmental impact: reducing plastic use in luer pressure sensors by 30% without compromising performance; decreasing paper consumption through the issuance of digital certificates for pressure and pH sensors; digitizing photometer processes to eliminate paper workflows; standardizing photometer electrical cable plugs for global compatibility to reduce material waste; and cutting packaging materials by 20%, lowering environmental impact related to transportation and waste. These efforts demonstrate our commitment to balancing environmental stewardship with operational excellence, empowering biopharmaceutical manufacturers to enhance productivity, meet regulatory requirements, and support global sustainability goals.

Through these initiatives, METTLER TOLEDO Pendotech exemplifies its dedication to sustainability, driving innovation that balances environmental responsibility with operational excellence. Our technologies empower biopharmaceutical manufacturers to enhance productivity, comply with stringent regulations, and support global sustainability targets, contributing to a healthier planet and a stronger biopharma industry future.



Luer pressure sensor original design and new product design

Conclusion

Embracing sustainable innovations in bioprocessing is no longer optional; it is crucial for achieving both environmental responsibility and operational excellence. Through the integration of flexible single-use systems and precise process monitoring, METTLER TOLEDO Pendotech remains committed to helping the industry overcome waste management challenges. By prioritizing these advancements, biopharma companies can ensure long-term growth and public trust while advancing the next generation of therapeutic development.

Sustainability

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