

# Driving Sustainable Biomanufacturing with Single-Use Technologies



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SPECIAL REPORT

# Driving Sustainable Biomanufacturing with Single-Use Technologies

## Integrating Life-Cycle Thinking and Collaborative Innovation

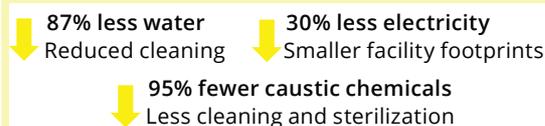
Lara Cobacho Lluesma, Yana Zelmanzon, and Magali Barbaroux

In 2015, the countries of the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development which included 17 Sustainable Development Goals (SDGs) across economic, social, and environmental factors. Biopharmaceutical companies are essential in supporting those goals, with SDG 3 (good health and well-being) often ranking as a top priority for its alignment with the industry's mission to end disease epidemics and reduce mortality through innovation and expanded access to healthcare. Single-use technologies (SUTs) play a key role by accelerating the development of new drugs and therapies — as demonstrated during the COVID-19 pandemic (1) — while also offering reproducibility, safety, flexibility, and time efficiency with reduced investment (2–4).

At the same time, the industry faces growing pressure to address its overall environmental footprint. The healthcare sector contributes 4.4% of total global emissions (5), prompting a collective response. In 2022, seven pharmaceutical chief executive officers (CEOs) announced a joint initiative to accelerate net-zero-emissions healthcare (6). Considering those efforts, SUTs increasingly are recognized not only for their operational benefits, but also for their potential to reduce environmental effects. Single-use implementation in biomanufacturing has been shown to support progress toward resource optimization, particularly for water, energy, emissions, and footprint reduction (2–4, 7, 8) (Figure 1). Additionally, development of new biomanufacturing methodologies and related technologies, such as process intensification (PI) enabled by SUT, further supports the reduction of bioprocess environmental impact (9).

While the environmental benefits of SUTs are increasingly recognized, their use also brings attention to plastic consumption in healthcare. Biomanufacturing-related plastic waste is estimated

**Figure 1:** Average resource conservation with single-use technologies (SUTs) compared with stainless steel facilities during the use phase as reported in the literature (5)



### Abstract

As the biopharmaceutical industry intensifies its commitment to sustainability, SUTs continue to play a pivotal role in transforming biomanufacturing processes. This article explores how Sartorius, together with industry partners, is advancing sustainable practices through innovation and life-cycle thinking. The Sartorius approach spans four key stages — beginning of life, production, usage, and end-of-life — with strategies that include incorporating bio-circular materials, using PFAS-free components, offering products that enable process intensification, and leveraging advanced data analytics tools. Together, these initiatives form part of a framework aimed at reducing the environmental impact of our products and our customers processes. Additionally, collaboration along the value chain is critical to achieving sustainability goals. To support this, Sartorius actively contributes to leading industry groups to co-develop standards, facilitate data sharing, and enable joint initiatives that help scale sustainable solutions for responsible bioprocessing.

to constitute less than 0.002% of the weight of global plastic waste (10, 11), offering perspective on SUT's role within the larger waste stream. Moreover, risk of uncontrolled plastic pollution from the biopharmaceutical industry is very limited due to strict regulations (12, 13). Still, Sartorius (a leading international partner to life-sciences research and the biopharmaceutical industry) remains committed to continuous improvement and

is advancing a product environmental sustainability concept, which includes:

- Prioritizing materials with low environmental impact, such as bio-circular materials.
- Reducing plastic use in products and packaging and optimizing resource efficiency.
- Advancing circularity by identifying opportunities to keep valuable materials in use and out of landfills, both within our facilities and in partnership with customers.

Those initiatives are supported by ongoing research and collaboration across the value chain in the spirit of SDG 17 (partnerships for the goals). By sharing knowledge and working together, Sartorius is contributing to a more sustainable future for biomanufacturing.

### A LIFE-CYCLE VIEW ON PLASTIC CIRCULARITY

At Sartorius, we use product carbon footprint (PCF) analysis as a strategic tool to pinpoint the climate change hotspots of our products. By understanding where the greatest effects occur, we can implement targeted ecodesign activities that reduce CO<sub>2</sub> emissions and enhance circularity, ensuring that our environmental sustainability efforts are both effective and measurable.

Building on those principles, Sartorius is working on circularity concepts to address every stage of a product's life:

- Beginning of life — We optimize material selection, consider circularity and recyclability in product design, and explore alternative feedstocks to reduce dependence on fossil resources and minimize environmental impact.

- Production — We implement measures to reduce scrap generation and recycle out-of-specification products internally.

- Product use — We provide products that optimize resource use throughout our customers' manufacturing processes.

- End of life — We develop strategies to divert products and packaging away from landfills and incineration.

The life-cycle approach ensures that environmental sustainability is embedded in every decision, supporting both environmental goals and the needs of our customers (Figure 2).

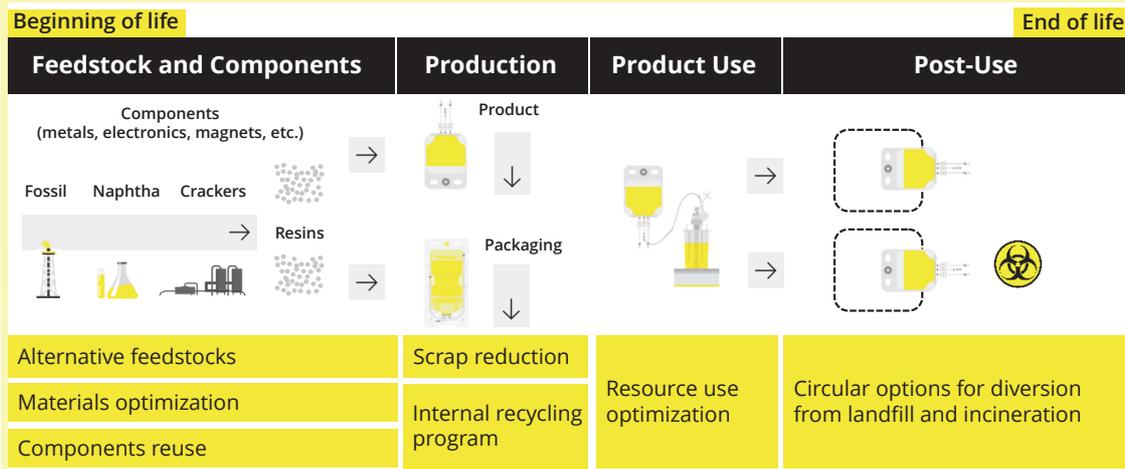
### SUT BEGINNING OF LIFE: ALTERNATIVE MATERIALS, OPTIMIZATION, AND SUPPLIER ENGAGEMENT

We recognize that choices made at this stage have a profound impact on the environmental footprints of our products throughout their life cycles.

The shift away from fossil-based plastics is a pillar towards decoupling raw material from finite fossil feedstock. We are incorporating bio-circular feedstocks — renewable materials derived from waste such as used cooking oil — into our products through a mass-balance approach. This allows renewable content to be tracked and attributed throughout the supply chain, ensuring that resulting polymers are chemically identical to their fossil-based counterparts and can be used without the need for revalidation.

To guarantee transparency and credibility, Sartorius has earned International Sustainability and Carbon Certification PLUS (ISCC PLUS)

**Figure 2:** Summary of challenges related to plastic waste throughout the life cycle of single-use technologies (SUTs) and corresponding Sartorius solutions to increase environmental sustainability



**Figure 3:** Sustainability features of Flexsafe bags for mixing, storage, and shipping

- Flexsafe Film designed to be fully recyclable
- Flexsafe Film with 71% certifiable bio-circular material
- Robust process validation and control to minimize scrap in manufacturing
- Magnets from operational waste are recycled and remolded into new impellers
- Change from pink to white foam to increase packaging recyclability



certification for key production sites in Aubagne (France), Stonehouse (UK), M’Hamdia (Tunisia), and Göttingen (Germany), with additional sites to follow in the coming months. That certification enables us to source renewable, certified raw materials for the manufacture of plastic components in SUTs, such as Ambr bioreactor vessels, Vivaflow filters, Flexsafe bags, and Sartopore Evo filters. By integrating ISCC PLUS–certified materials, we are helping our customers meet their sustainability goals without compromising product quality or performance.

Another key initiative at the design phase is selecting materials that can be recycled. For example, the Flexsafe film was developed to be mechanically recyclable (Figure 3). We also consider SUT waste in our approach to product design, such as in high-impact areas (e.g., filtration). Sartopore Evo filters, our latest generation of sterilizing-grade filters specifically designed for fill–finish applications, exemplify that approach. The filters are based on a tried and proven polyethersulfone (PES) membrane with an innovative surface modification that minimizes the adsorption of proteins and excipients such as polysorbates. That helps to ensure stable drug formulations and reduces the number of vials discarded during fill–finish operations.

Unlike traditional polyvinylidene fluoride (PVDF) membrane filters, Sartopore Evo filters do not use per- and polyfluoroalkyl substance (PFAS) compounds, which are a group of synthetic chemicals also known as “forever chemicals” that persist in the environment and are linked to health risks (14). With PFAS eliminated from their materials of construction, Sartopore Evo filters support Sartorius’ commitment to chemical safety and environmental responsibility. Additionally, Sartopore Evo cartridges operate at significantly higher flow rates and throughputs than PVDF filters can achieve, enabling the use of relatively small filter elements.



**Photo 1:** The R&D building of the Sartorius Campus in Göttingen is Germany’s first DGNB platinum laboratory, setting a sustainability benchmark.

That capability further reduces adsorption, required rinse volumes, and disposable waste (Figure 4).

Those innovations in material selection and product represent an important step in Sartorius’ journey towards circularity. However, achieving meaningful sustainability outcomes requires more than internal advancements; it demands a shared commitment across the entire value chain. To support that initiative, Sartorius has developed its *Sustainability Supplier Handbook*, a comprehensive guide outlining the minimum requirements expected from suppliers and setting clear targets for environmental, social, and governance (ESG) performance (15). By fostering close collaboration and sharing best practices, the company encourages innovation and development of sustainable solutions. That strategic framework goes beyond compliance, aiming to build meaningful partnerships across the supply network and drive sustainable transformation.

### **SUT PRODUCTION: SUSTAINABILITY IN PRACTICE ACROSS OUR SITES**

Environmental sustainability in production is not just a goal; it’s a daily practice embedded in the

largest Sartorius SUT manufacturing sites. All of the company's major facilities operate under ISO 14001 certification, ensuring systematic environmental management and continuous improvement.

Recent expansions in Aubagne and Göttingen were designed to meet stringent sustainability standards and consequently have earned prestigious recognition. Göttingen's new research building (Photo 1) is the first laboratory in Germany to achieve DGNB Platinum certification, which is the highest rating from the German Sustainable Building Council. The building sets a benchmark for sustainable construction with features such as one of the country's largest geothermal energy systems for heating and cooling. Additionally, the site purchases 100% renewable electricity. Complementing those efforts, the site recently obtained ISCC PLUS certification, enabling the use of bio-circular and recycled plastic drop-in solutions for products by companies adhering to the mass-balance approach.

Aubagne has earned Haute Qualité Environnementale (HQE) "Excellent" certification for sustainable building design, the BiodiverCity label, and ISCC PLUS certification. The site combines advanced production capabilities with environmental responsibility, including a strong focus on circularity and fully electric production processes powered by 100% renewable electricity. Since 2018, the site has reduced production rejects by 60%. In addition, it recycles 84% of its production waste and is on track to achieve zero waste to landfill in 2026.

Circularity also extends to resource-intensive processes. Membrane production relies on substantial chemical volumes, making recovery and reuse essential for reducing the overall environmental footprint of membranes. Sartorius has installed distillation plants in Göttingen and

**EXPERT INSIGHT:** "We've demonstrated that process intensification has a significant positive impact on sustainability, reducing waste and energy use. These improvements also align with the industry's goal of lowering costs." —Behnam Partopour, Sartorius

Yauco (Puerto Rico) to enable recycling of solvents from production water and reuse of those critical resources. That approach also reduces environmental risk because some solvents fall under the classification of hazardous substances.

By incorporating environmental sustainability principles into production processes — including renewable energy, circular material flows, and solvent recovery — Sartorius works to ensure that each site contributes to shared goals of reducing emissions, enhancing circularity, and conserving resources.

### **SUT USE: ENABLING EFFICIENT, INTENSIFIED, DATA-DRIVEN BIOMANUFACTURING**

To further advance sustainability and efficiency in biomanufacturing, Sartorius has developed products that embrace two powerful bioprocess-optimization strategies: PI and advanced data analysis. PI transforms conventional batch production into streamlined, continuous workflows. In a recent study, an end-to-end continuous process was compared with best-in-class intensified fed-batch production for monoclonal antibodies (mAbs) in

**Figure 4:** Sustainability features of Sartopore Evo filters

- Designed to function without the intentional use of PFAS
- 100% bio-circular polypropylene in cartridges \*
- Higher flow rates than PVDF, enabling the use of smaller filter elements, further reducing adsorption and minimizing disposable waste
- Scrap reduction initiatives in manufacturing
- 90% recyclable packaging

\* 5" cartridges will be certified in the near future



## INDUSTRY VOICE:

“Collaborating with Sartorius on the development of the Pionic Platform has enabled us to explore new frontiers in continuous downstream processing (DSP). This flexible, commercial-ready solution supports intensified DSP and aligns with our sustainability goals by increasing manufacturing output in a reduced facility footprint.” —Kevin Brower, Sanofi

multiproduct facilities. The analysis, covering economic and environmental sustainability modeling, as well as uncertainty simulations, revealed significant advantages of continuous processing. Production costs can be reduced by up to 23%, facility footprints can shrink by as much as 51%, plastic waste can decline by up to 57%, and CO<sub>2</sub> emissions can be lowered by up to 54%. Those improvements stem from using equipment efficiently, limiting changeovers, and reducing energy and material consumption (16, 17).

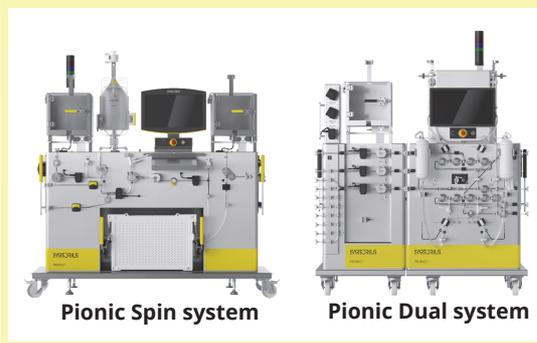
Continuous processes also enhance flexibility by enabling facilities to adapt quickly to market shifts while maintaining consistent product quality. Sartorius drives this transformation with advanced platforms that simplify and accelerate the transition to integrated continuous bioprocessing. For upstream operations, Biostat STR bioreactors with Flexsafe STR bags simplify setup while enabling superior process control and integrated automation, boosting productivity and reducing cost per gram. For continuous downstream processing, Pionic platform integrates key unit operations into a modular, automation-ready platform designed for extended process duration, making efficiency and environmental gains accessible to biomanufacturers. (Figure 5)

Complementing PI gains, data analytics offers another powerful lever for advancing environmental sustainability in biomanufacturing. Such technologies strengthen those efforts by

## INDUSTRY VOICE:

“Sustainability is closely tied to your operational footprint, and with our continuous platform, that footprint is much smaller. We’re seeing clear sustainability gains, about 40 to 50% improvement compared to standard fed-batch processes.”  
—Himanshu Gadgil, Enzene

**Figure 5:** Integrated continuous biomanufacturing with Pionic



transforming process data into actionable insights, especially when powered by SIMCA multivariate data-analysis software. Widely adopted in the biopharmaceutical industry, that tool supports process optimization and quality control. SIMCA software enables predictive modeling that not only improves process robustness, but also identifies opportunities to reduce emissions, electricity demand, and production waste.

By leveraging existing infrastructure, SIMCA minimizes barriers to implementation while delivering measurable environmental benefits. For example, its application has resulted in over US\$1.4 million in annual fuel savings at Michigan State University, cutting >10,000 metric tons of CO<sub>2</sub> emissions each year. In addition, SIMCA has supported a 27% reduction in peak electricity use during high-demand periods, earning \$127,000 in energy credits at one plant and validating the approach for broader adoption. Beyond energy savings, SIMCA-driven insights have improved predictive maintenance and process efficiency,

**Figure 6:** Sustainability features of Ambr vessels

- 🏠 Bio-circular material: Ambr 15 (83%), Ambr 250 (49%)
- 🏠 100% recyclable packaging
- 🏠 Scrap reduction initiatives in manufacturing
- 🏠 Product recyclability proven at laboratory scale and pilot-scale evaluation is under consideration
- 🏠 Prioritizing sea shipping to save on CO<sub>2</sub> emissions



helping to prevent waste batches and minimize water consumption. Those outcomes demonstrate how advanced analytics align with environmental goals while enhancing operational performance.

### **SUT END OF LIFE: ADVANCING CIRCULARITY AND REDUCING ENVIRONMENTAL IMPACT**

Although SUTs have enabled more efficient and intensified biomanufacturing, their end-of-life management remains a critical challenge. The prevailing approach — waste to energy — often lacks proper sorting and decontamination, fails to address greenhouse gas (GHG) emissions, and can result in the loss of valuable plastic materials.

To overcome such limitations, Sartorius is exploring innovative recycling concepts for enhancing circularity and minimizing the carbon footprint of post-use SUT components. That involves:

- Sorting — separating hazardous and nonhazardous SUT waste to enable targeted recycling.
- Mechanical recycling — reprocessing consumables such as Flexsafe bags and Ambr vessels using mechanical methods.
- Advanced recycling — investigating chemical, mechanochemical, and other technologies for components that are not suitable for mechanical recycling.

Mechanical recycling generally is preferred among post-use SUT management solutions for its favorable emission and economic profiles. However, concerns about the consistency of quality and material properties often impede adoption. To address that concern, Sartorius has implemented lab scale projects to demonstrate the feasibility and benefits of mechanical recycling for two major SUT consumables: Flexsafe film and Ambr vessels.

The R-Flexsafe project was developed in collaboration with Sanofi and Veolia (18). It focuses on recycling Flexsafe film, which is the primary

**EXPERT INSIGHT:** “Our analytics tool helped Michigan State University optimize their energy use and achieve significant savings. By reducing emissions and operating more efficiently, companies not only lower their environmental impact but also benefit financially, such as earning energy credits from utility providers.” —Bob Davis, Sartorius

material for a breadth of Sartorius single-use bags. The target focus was the recycling of non-cell contact bags. After recycling, the material exhibits properties comparable to virgin low-density polyethylene (LDPE), making it suitable for applications such as films, pipes, fittings, profiles, and flexible sheets.

The R-Ambr project was implemented in partnership with Covestro (19). It targets the recycling of Ambr vessels — small-scale bioreactors mainly used in research and process development (Figure 6). Testing confirms that the recycled material maintains cell compatibility under standard culture conditions, validating its possible use in the same applications as virgin material. Based on that project, we collaborated with an end user to test whether postconsumer recycled Ambr vessels can perform as well as virgin plastic in cell culture applications. The findings demonstrate that using recycled polycarbonate (PC) reduces the

environmental footprint of the vessels and does not adversely impact vessel extractables. Even in direct contact with cells and media, recycled PC left cell culture performance and mAb production largely unaffected. A new study on this topic will be published soon.

Work is ongoing to establish dedicated waste streams that support at scale recycling of SUT components. However, achieving circularity in SUTs will demand coordinated action across the value chain. Technology providers must design SUTs for recyclability and collaborate with recycling partners to develop and implement viable processes. End users will play a key role in collecting and decontaminating post-use waste, whereas recycling partners must ensure material quality to enable reintegration of recovered plastics into new plastic-resin production cycles.

### **INDUSTRY COLLABORATION: DRIVING SUSTAINABILITY THROUGH PARTNERSHIP**

As highlighted above, achieving circularity in SUTs requires a collective industry commitment and coordinated action across the value chain. Sartorius is leading and participating in such efforts by working alongside peers, suppliers, and end users to accelerate progress and share best practices. We are active members of several industry groups dedicated to advancing sustainability in biomanufacturing. Below we highlight recent collaborations in which Sartorius has coauthored publications specifically focused on SUT sustainability and circularity.

One notable example is our work within BioPhorum's sustainability workstream, through which Sartorius contributed to a landmark report on estimating the volume of SUT waste produced in mAb drug-substance manufacturing (20). That publication provides the first robust quantification of SUT waste in biomanufacturing and underscores the importance of data sharing and multiorganizational collaboration to reduce environmental impact and develop scalable recycling solutions.

Similarly, through the International Society of Pharmaceutical Engineering (ISPE) disposables/single-use community of practice, Sartorius has participated in technical publications and industry surveys that assess current SUT waste management practices in biomanufacturing and highlight opportunities for improvement (21). The ISPE survey results reveal a strong industry commitment to recycling and a willingness to invest in better end-of-life solutions, but also make clear that real progress depends on collaboration among manufacturers, end users, and recyclers.

**INDUSTRY VOICE:** "Sartorius identified the potential for recycling, so we collaborated with a third-party recycler, Covestro, to recover the polycarbonate from real cell culture vessels used in our R&D lab. Sartorius reconstituted it to make new vessels, and we've demonstrated that recycled material performs comparably to virgin plastic in cell culture applications."

—Eric Sorge, Merck & Co.

**INDUSTRY VOICE:** "Achieving sustainability won't happen without collaboration.

A typical customer-supplier relationship is just a small part of the solution. To close the loop and lower carbon footprints, more parties need to be involved." —Pierre Moulinié, Covestro

Our engagement extends to the National Institute for Innovation in Manufacturing Biopharmaceuticals (NIIMBL) sustainability workstream, through which Sartorius has helped to develop a life-cycle assessment tool for evaluating environmental impacts throughout mAb production life cycles. Early models indicate that continuous processes can reduce carbon emissions significantly, primarily by lowering energy consumption in small facilities. Ongoing work is focused on refining those models with realistic manufacturing data, further supporting industry-wide sustainability goals.

**INDUSTRY VOICE:** “At BioPhorum, we recognize that achieving sustainability in biomanufacturing requires collective action. Contributions from companies like Sartorius demonstrate the importance of broad industry engagement. This level of participation is essential to develop scalable solutions that reduce environmental impact across the biopharma sector.”—Nicola Coles, BioPhorum

In addition, Sartorius is chairing the sustainability committee of the Bio-Process Systems Alliance (BPSA), contributing to educational assets such as an infographic titled “Single-Use Technologies (SUTs) Improve Healthcare Outcomes and Reduce Environmental Impacts” (5).

Through such partnerships and published assets, Sartorius is helping to build the data, tools, and frameworks needed for a circular SUT ecosystem. By sharing knowledge and working alongside industry peers, we are accelerating progress toward sustainable biomanufacturing.

## KEY TAKEAWAYS

Sustainable bioprocessing is no longer a distant goal. The biopharmaceutical industry is making significant progress into sustainable production, with Sartorius supporting this challenging yet crucial journey. Sartorius is contributing to that transformation by embedding environmental sustainability into every stage of the SUT life cycle, from material selection and product design to manufacturing, use, and end of life.

PI enabled by SUTs has become a cornerstone of that shift. By transitioning to continuous bioprocessing and leveraging data analytics, emissions, energy consumption, and plastic waste can be reduced significantly while cost efficiency and product quality are improved. Such gains deliver

both environmental and economic benefits, supporting broad access to biologics and vaccines through small, agile manufacturing footprints. Simultaneously, Sartorius is advancing circularity through several initiatives, including the introduction of bio-circular materials and exploring mechanical-recycling solutions.

Cross-sector partnerships are crucial in building the infrastructure and knowledge needed to scale sustainable solutions. Together, life-cycle thinking and industry-wide collaboration are shaping a new model for biomanufacturing, one that delivers environmental performance, economic value, and global health impact.

To learn more about the sustainability attributes of Sartorius SUTs, visit our Product Sustainability webpage

## ACKNOWLEDGMENTS

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