Single-use technology and sustainability: quantifying the environmental impact in biologic manufacturing

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Single-use technologies offer a variety of productivity and flexibility benefits to biopharmaceutical manufacturers. However, they are often perceived as being bad for the environment due to perceptions around disposal of consumables. This white paper presents results from GE Healthcare's 2016–2017 Life Cycle Assessment (LCA) study, which considers the entire value chain and multiple environmental impact categories. The data show that single-use technologies usually result in lower environmental impacts compared to traditional stainless steel and that end-of-life disposal of single-use components has minimal impact compared with other factors such as energy and water use in the production phase. Another finding is that the geographic region where single-use equipment is located and the cleanliness of the electrical grid strongly influence the environmental impact. The LCA model can be very useful for evaluating and prioritizing improvement opportunities within a given process technology (i.e., traditional, single-use, or hybrid).

Introduction

Biopharmaceutical development and manufacturing continues to be very complex and highly competitive. Biomanufacturers are challenged with a need to focus on more targeted therapies, cost pressures for existing processes, and increased localization of manufacturing.

Biomanufacturers want to be more productive. They are looking to maximize yield, use existing assets more flexibly, and reduce variability, all while increasing both efficiency and quality. Over the past decade, single-use technologies have enabled biomanufacturers to achieve many of these outcomes, offering benefits of flexibility, minimized cleaning, and process economy.

One potential concern about single-use technologies centers around sustainability. There is a common belief that single-use technologies might be harmful to the environment because of consumables potentially ending up in landfills. In order to understand end-of-life and other impacts across the entire life cycle of the biomanufacturing process, GE Healthcare has conducted detailed LCA studies. This white paper presents some of the key results from our ongoing 2016–2017 study.

Sustainability

Climate change, water scarcity, and energy and resource management have become important topics across industries. In the biopharmaceutical industry, sustainability is one of six major industry trends (1, 2). Some drivers for sustainable development are employee awareness and values, a more stringent regulatory environment, investor expectations, and other factors (3).

One area within industry control is the environmental impacts of manufacturing (3). The technology shift away from stainless steel and towards single-use equipment in biomanufacturing provides an opportunity to understand the environmental impacts and communicate them to stakeholders.

Evaluating sustainability holistically

At GE Healthcare we take a holistic approach to evaluating sustainability, using an internationally recognized methodology called Life Cycle Assessment (4, 5). We assess the environmental impact throughout a product's life cycle, from resource extraction, processing, manufacturing, through the end of the product's life. In addition to considering the entire value chain, we also evaluate a variety of impact factors. The focus on multiple life cycle stages allows us to gain insight regarding burden shifts from one life cycle stage to another. In this work we look at impacts on climate, energy, and water, as well as several aggregated "damage" categories in which various impacts are grouped with respect to their damage to ecosystem quality, human health, or natural resources (Fig 1).

2016–2017 LCA study for an evolving biopharmaceutical industry

Several years ago we performed a detailed LCA study focusing on GE Healthcare's WAVE Bioreactor™ and ReadyToProcess™ single-use fluid management technologies for monoclonal antibody (mAb) production (6). The 2010–2012 LCA study revealed the surprising result that switching to single-use technologies significantly reduces use stage (bioprocess operation) impacts (primarily due to water and energy savings), resulting in a significant net overall life cycle benefit compared to traditional bioprocessing equipment. This result was counterintuitive and led to a changed environmental perspective on single-use bioprocessing technology within the industry. This study was subjected to a third-party critical panel review and was published in a peer-reviewed technical journal (7).

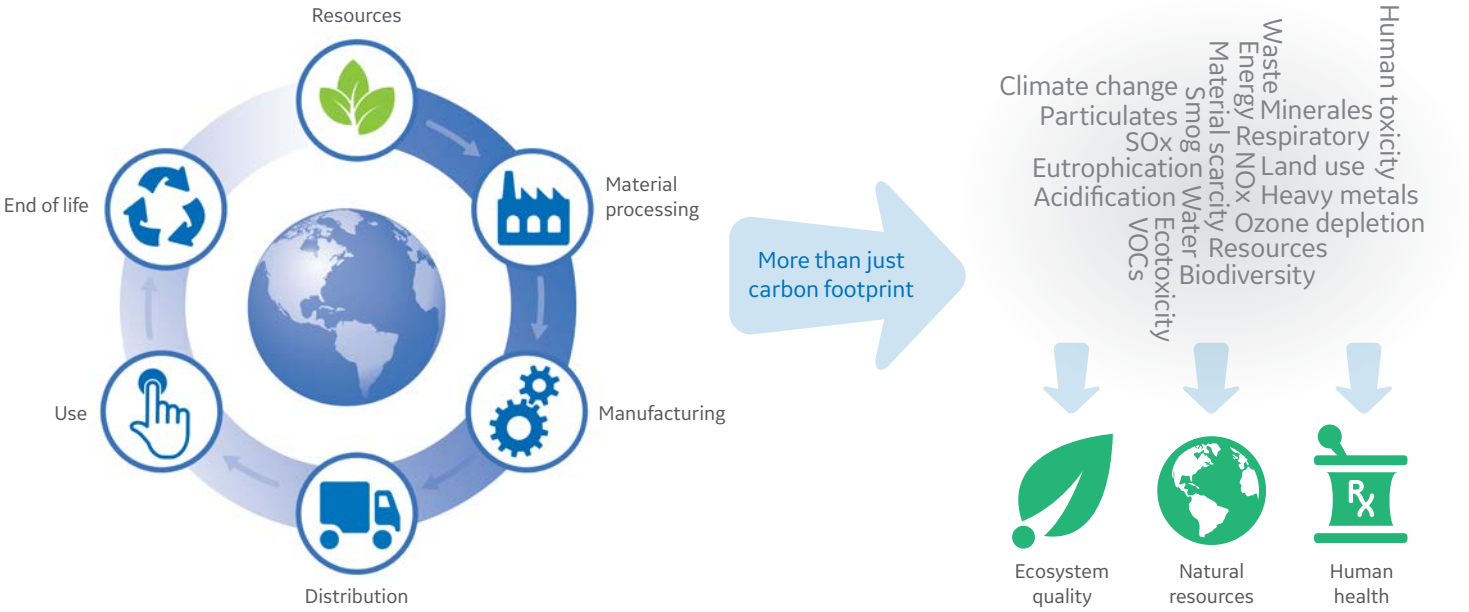

Fig 1. Schematic diagram of the product life cycle (left) and impacts evaluated in Life Cycle Assessment (LCA). LCA is a powerful approach that allows one to evaluate environmental impacts, benefits, trade-offs, and burden shifts across the product life cycle, from cradle-to-grave.

Since we performed the original LCA study, the biopharmaceutical industry has continued to evolve. Biomanufacturing is expanding globally, needs for maximizing utilization while minimizing footprints are increasing, and new single-use technologies are available. These factors, along with many questions from the biopharmaceutical industry, are the drivers for us to perform an updated LCA study. The parameters in the original and new study are presented in Table 1.

Table 1. Parameters for original vs. 2016-2017 LCA study

	2010–2012 study	2016–2017 study
Molecule or particle to be manufactured	Monoclonal antibody (mAb) only	Monoclonal antibody (mAb) Adenovirus (AdV) vaccine
Process technology	100% single-use (SU) retrofit 100% stainless steel (SS) traditional	100% single-use (SU) retrofit 100% stainless steel (SS) traditional Hybrid
GE Healthcare single-use products	WAVE Bioreactor ReadyToProcess fluid management portfolio	WAVE Bioreactor ReadyToProcess fluid management portfolio Xcellerex™ XDR bioreactors Xcellerex XDUO mixers HyClone™ portfolio ÄKTAready chromatography system ReadyToProcess prepacked chromatography columns
Geography	US Average	Boston, Massachusetts, USA California, USA Sao Paulo, Brazil Istanbul, Turkey Shanghai, China Dortmund, Germany Cork, Ireland
End-of-life options	Incineration	Autoclave-landfill Shred-autoclave-landfill Incineration Incineration with energy recovery Recycling
Campaign type (mAb)	6 g/L 10-batch campaign	6 g/L 10-batch campaign
Process scales	mAb 100 L mAb 500 L mAb 2000 L	mAb 200 L mAb 500 L mAb 2000 L mAb 2 × 2000 L mAb 4 × 2000 L AdV 50 L AdV 200 L AdV 500 L

SU = single-use; SS = stainless steel

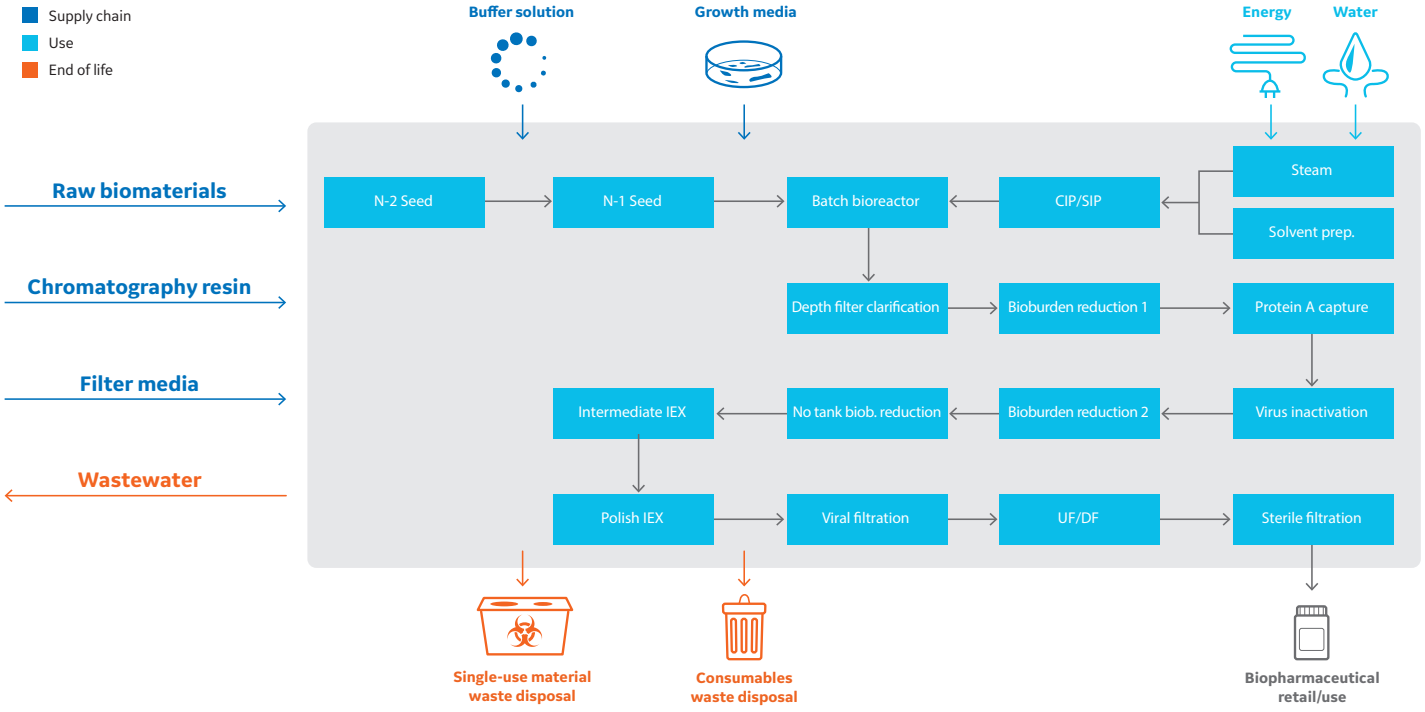

Fig 2. mAb bioprocessing configuration used in current study. Biob. = bioburden, CIP/SIP = cleaning/sanitization in place, IEX = ion exchange chromatography, Prep. = preparation, UF/DF = ultrafiltration/diafiltration. Note: General unit operations shown; configuration can change due to scale, product choice, technologies used, etc.

In this LCA study, we account for everything coming into and leaving the bioprocess. Our LCA model is quite granular – we are looking at each individual unit operation within the bioprocess configuration, as well as support systems such as CIP/SIP (Fig 2).

To perform the study, first we collect data about all of the inputs and outputs (energies, masses, activities, equipment, transport) – known as the Life Cycle Inventory (LCI). The LCI feeds into an impact assessment method that translates the LCI data into midpoint environmental impacts. These are then further aggregated into the three damage categories (8).

In this study we tend to focus on three midpoint categories (carbon footprint, energy footprint, water footprint) that provide the reader with direct, easily understandable metrics. We also tend to focus on three damage categories (human health, ecosystem quality, and natural resources) to ensure that we are addressing a comprehensive range of potential impacts.

2016–2017 LCA study* results and discussion

There are many different scenario permutations in our LCA model, and it is challenging to fully convey the results in one sitting. Therefore, we are selectively presenting results that offer key sustainability trends and insights.

The first scenario compares impacts of traditional stainless steel and single-use process configurations for a 2 × 2000 L mAb process in Istanbul, Turkey. Figure 3 presents the distribution of impacts across three broad life cycle stages: supply chain, use (i.e., bioprocess operation), and end-of-life.

The single-use technologies show lower impact compared to traditional stainless steel in each of the five impact categories presented.

The results indicate a burden shift: the single-use process technologies show significantly lower use-stage impacts (primarily due to reduction in the need for CIP/SIP and between-batch cleaning and sterilization) but higher supply chain impacts (manufacturing and distribution of single-use consumables). The exception is water consumption, where there is no burden shift because the majority of water impacts occur during use regardless of the choice of process technology. The end-of-life impacts (in orange) are negligible compared to other impacts.

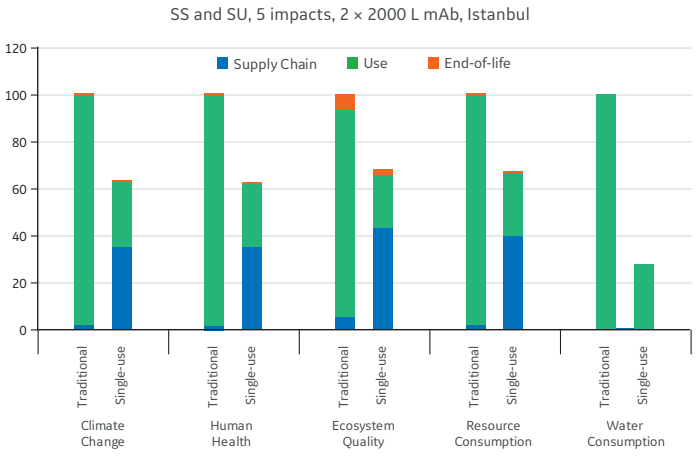

Fig 3. Impact comparison for traditional and single-use process technologies. Data are for a 2 × 2000 L scale mAb process located in Istanbul, Turkey. End-of-life disposal is autoclaved followed by landfill.

* Third-party critical panel review per ISO 14040-44 is in process

Figure 4 looks at the effect of process scale on per-unit impacts. The results clearly show that the environmental impacts per unit of mAb production decrease as one moves from smaller scales up to clinical and production scales. This is important as the industry shifts biopharmaceutical production to single-use process technology.

We can also look at the effect of geography. Figure 5 demonstrates that geography has a strong effect on climate change impacts. The two most impactful variables related to geography are: (1) how "green"* the electricity grid mix is in a given geography; and (2) transport logistics – in our LCA model, we are shipping components via air to other continents, and air tends to have a fairly high environmental impact compared to road, rail, or ship. It is important to note that supply chain logistics can and will change, so this is just a snapshot in time.

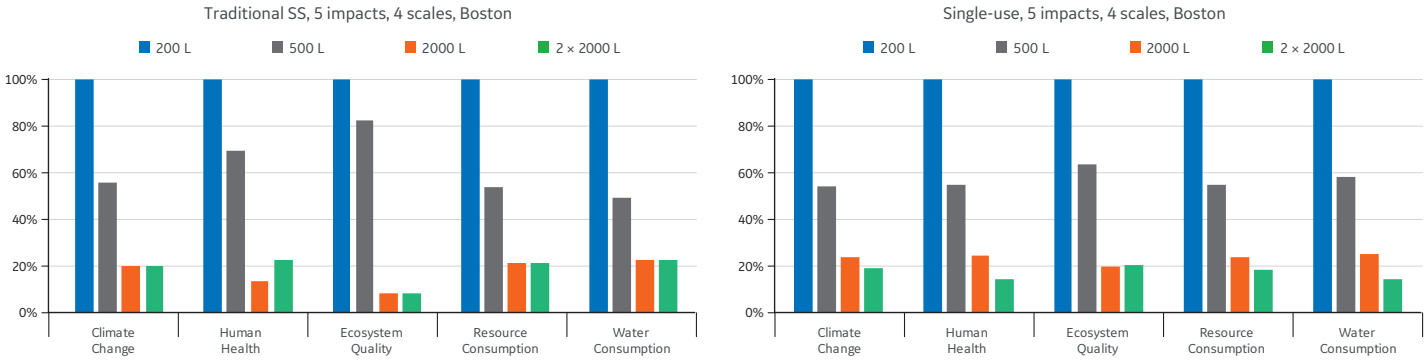

Fig 4. Impact comparison for traditional and single-use process technologies at four process scales, from 200 L to 2 x 2000 L mAb production. Location is Boston, USA, and end-of-life disposal is autoclaved followed by landfill.

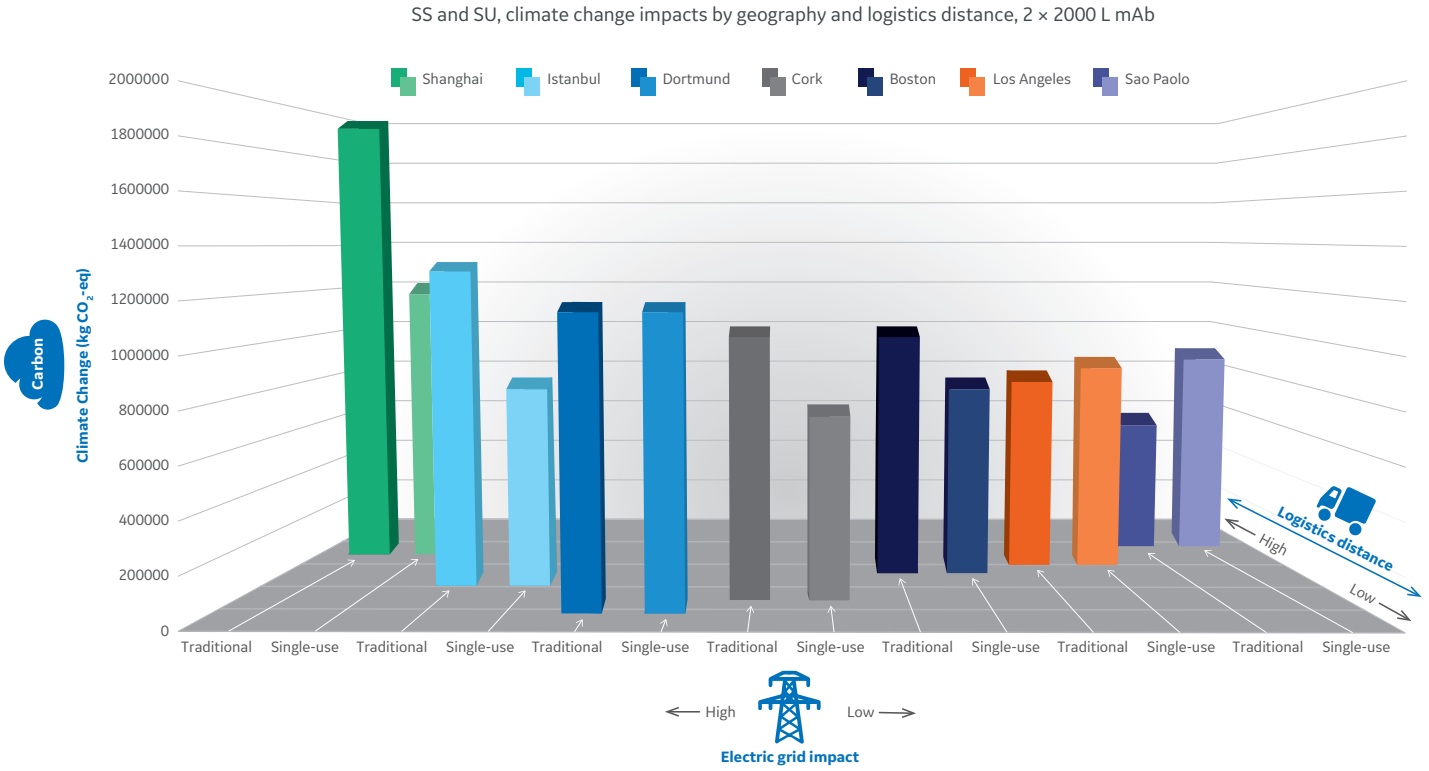

Fig 5. Comparison of climate change impact (y-axis) between traditional and single-use mAb bioprocess by siting geography, ranked by logistics distance (z-axis) and electricity grid impact (x-axis). On the x-axis, the geographies are arranged left-to-right in terms of the 'green-ness' of the electricity supply in each region. On the z-axis, the geographies are arranged front-to-back in terms of transport logistics intensity; those bars placed closer to the front axis have relatively low-impact transport logistics, while those placed towards the back have relatively high-impact transport. Data are for a 2 x 2000 L mAb process. End-of-life disposal is autoclaved followed by landfill.

* The "green-ness" of the electricity grid in a given region depends on the mix of electricity-generating technologies feeding into the grid mix. For example, an electricity grid comprised mostly of renewable energy sources (e.g., hydro, solar, wind) will have a lower environmental "footprint" compared to a region that relies heavily on the burning of fossil fuels to generate electricity.

Looking from left to right, as we shift towards regions with cleaner electricity grids, the difference between single-use and traditional decreases, and can even toggle. However, transport logistics are also an important variable here. For example, the results for Sao Paolo are mainly a reflection of increased transport logistics for single-use compared to traditional. This result is revealed because in that region, energy is a level playing field with no clear benefit to either technology choice. Notably, more than 70% of electricity in this region comes from hydropower.

If we look at freshwater consumption (data not shown), single-use is always better than traditional, regardless of geography, electricity grid, or transport logistics distances.

We can also examine the combined effects of process scale and geography on freshwater consumption (Fig 6). Here we look at traditional compared with single-use (blue data points). In this ratio plot, if the data point is above "1", then single-use is better (i.e., lower environmental impact) compared with traditional. In all cases, single-use process technologies are better than traditional.

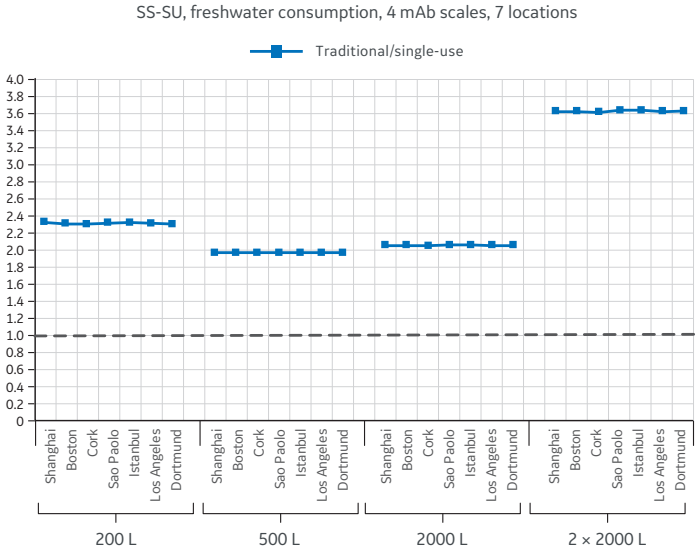

Fig 6. Ratio of the freshwater consumption impact for the mAb process configurations, differentiated by installation geography and process scale.

Figure 3 illustrated that end-of-life impacts are negligible in the context of the full life cycle. Nevertheless, this is an important aspect to consider, because the solid wastes that are generated require proper disposal. For that reason, the next LCA result looks at a variety of end-of-life (EOL) disposal options. Figure 7 re-affirms that end-of-life impacts are indeed negligible, here shown for a 200 L and a 2 × 2000 L scale single-use mAb process. Recycling, landfill, and incineration with energy recovery tend to be better options than incineration.

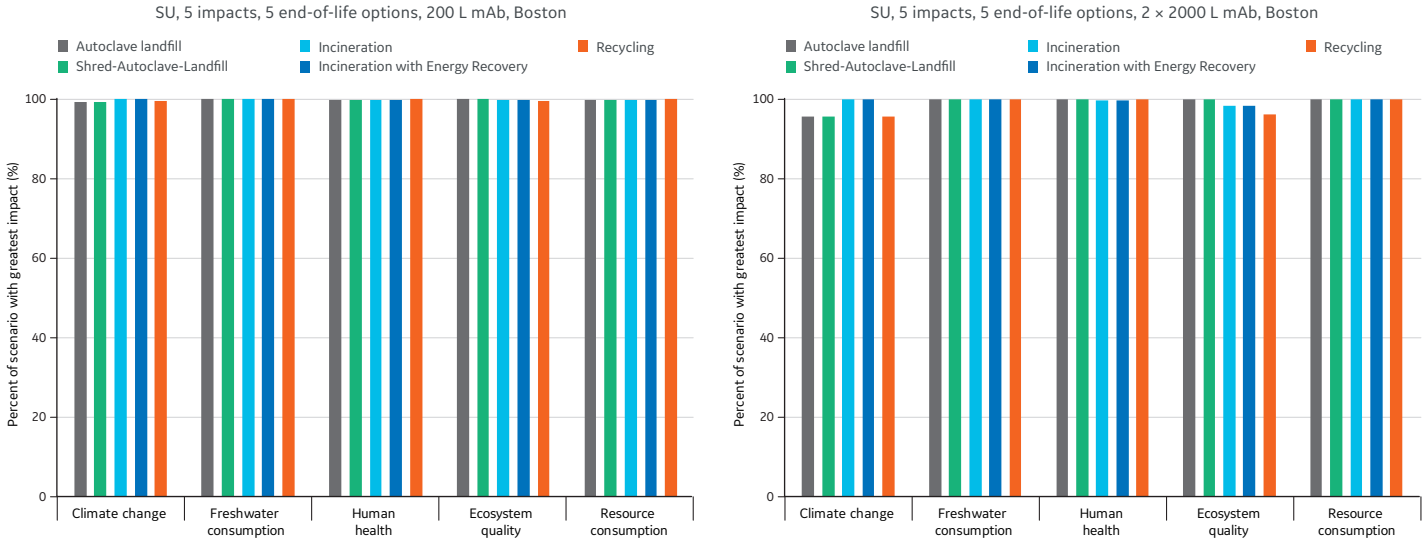

Fig 7. Comparative life cycle environmental impact for alternative end-of-life disposal options for single-use mAb process in Boston, USA at the 200 and 2 × 2000 L scales.

Summary

Strategic insights from the 2016–2017 study so far are that mAb scenario results are sensitive to geography. Specifically, traditional stainless steel processes are highly sensitive to the cleanliness of the electrical grid. Also, single-use processes are sensitive to both the electrical grid and the transport logistics. mAb results for both traditional and single-use processes are sensitive to scale; impacts per unit mAb decrease with increasing production volume. Finally, end-of-life disposal of single-use materials does not contribute significantly to overall life cycle environmental impact.

Overall, single-use process technology is often less environmentally impactful than traditional for mAb processes, with some exceptions based on a combination of geography and process scale. We recommend using caution when extending these findings: The complex relationships between key influencing variables might require exploration of results specific to a given scenario.

This is an ongoing, collaborative study addressing customer sustainability questions. Contact GE Healthcare with your questions.

About GE and bioprocess sustainability

GE is a global company serving many industries and believes the right way to do business is to do it sustainably. When it comes to bioprocessing, GE has led the market in understanding the environmental impact and sustainability shift when moving from stainless steel to single-use technologies. The insights we have gained around the environmental sustainability of bioprocess manufacturing will factor into our plans as we evolve. For example, one area that we are currently focusing on is streamlining the supply of single-use film for bioprocess. The new Fortem™ single-use film platform simplifies qualification and supply management while offering a secure supply chain that is committed to operational efficiency and sustainable practices.

Acknowledgements

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