Intensifying Upstream Processing

Implications for Media Management

SARTORIUS

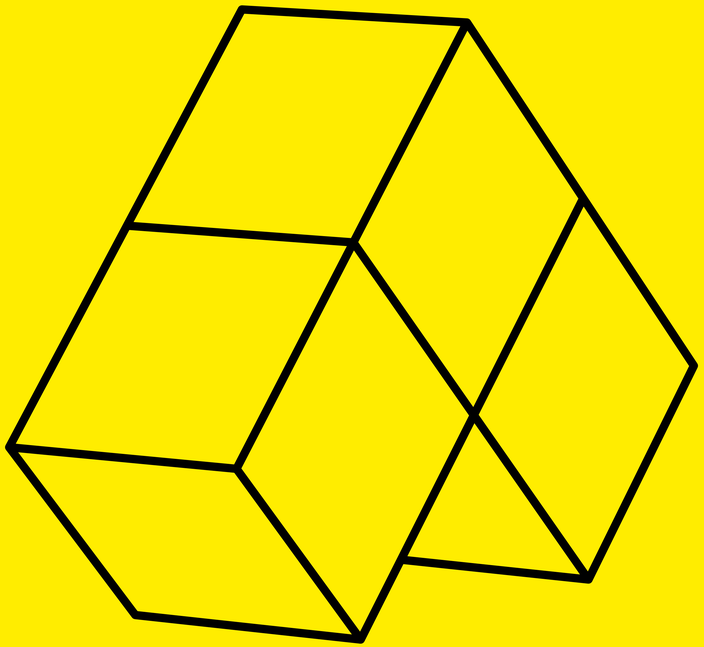
Abstract

Biopharmaceutical development and production require the investment of significant time and resources. Manufacturing procedures must be efficient, robust, and productive to minimize failure risk and ensure targets are met.

Operational modifications that intensify upstream processing allow manufacturers to maximize their output without significantly altering their production approach. Effective process intensification (PI) strategies can enhance several measures of efficiency, including faster drug development, increased productivity of GMP manufacturing, reduced footprint, enhanced flexibility, and improved quality. The best PI approaches will combine and deliver several of these benefits, allowing biologics manufacturers to remain competitive. However, adopting (PI) might introduce some additional challenges, such as effectively managing increased media volumes.

Here, Sartorius provides biotherapeutic developers with the tools and knowledge to confidently explore their intensification options. First, we discuss the benefits of implementing PI before exploring the potential implications on media management. We then outline the value in conceptual design to assist with the logistics of the media journey. Finally, we review the feasibility of implementing different PI scenarios in both existing and new facilities.

Table of Contents



Introduction

Process Intensification

Process intensification (PI) describes a comprehensive approach to maximize the efficiency of biomanufacturing. PI can be applied to individual unit operations by implementing changes to improve the productivity of that step, or to the whole process by applying various changes both up and downstream. PI can also be implemented at the level of an entire facility, resulting in a modular setup.

Several barriers can block the adoption of PI in both new and established facilities, including lack of experience, managing new regulatory requirements, limited availability of technology, and resistance to change.

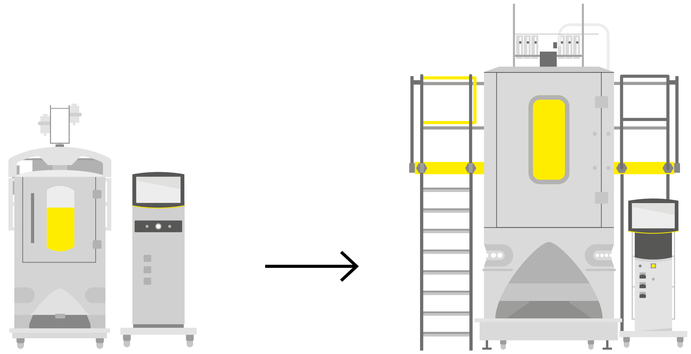
However, the trends and challenges in the biopharmaceutical industry continue to push manufacturers towards solutions offered by PI:

- Increasing economic pressures drive the need for lower costs of goods and costs of development, which could be achieved by moving towards intensified process platforms with better efficiency.
- Market and patient demands can be unpredictable; flexible solutions are required to cope with changing customer needs and the production of small volumes.
- Innovations in biotherapeutics' development have initiated a move towards less stable modalities (e.g., bispecific monoclonal antibodies) that are sensitive and more complicated to manufacture.

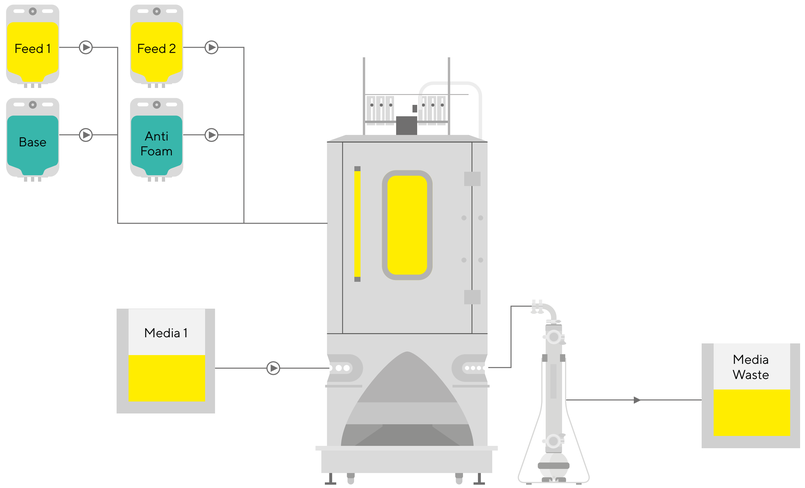
Getting the most out of the existing process while simultaneously lowering the cost of goods and meeting customer demands are the primary motivators when making modifications to a manufacturing process. Intensification strategies could involve adapting existing facility layouts and operations to support higher throughput and more productive manufacturing.
For those earlier in their biopharmaceutical journey, adopting PI could require the development of an entirely new strategy with intensification solutions applied throughout. However, implementing these changes could create many unknowns and require considerable, disruptive modifications to current operations.

The upstream cell culture process is one of the key areas in which PI strategies are most effectively evaluated and executed (Figure 1). However, the modifications have significant consequences for handling cell culture media throughout manufacturing, facility operations, and layout.

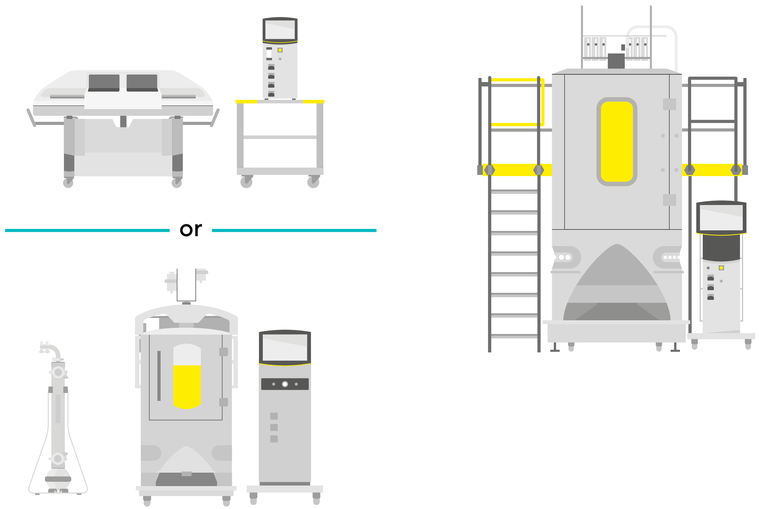
1 Standard Fed-Batch



3 Intensified Approaches – Concentrated Fed-Batch



2 Intensified Approaches – N-1 Perfusion



4 Intensified Approaches – Dynamic Perfusion

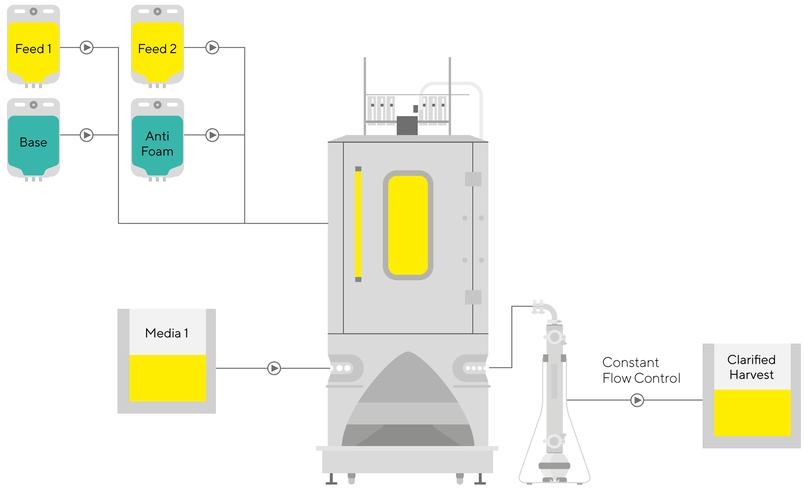


Figure 1
Upstream Process Intensification Scenarios

1 The standard cell culture technique used across the biopharmaceutical industry is fed-batch culture. In fed-batch processes, cells are cultured in a bioreactor, typically for 14 days. Protein harvest happens only at the end of the fed-batch. Feed media is added gradually to replenish nutrients and growth factors during the process.

2 Seed train intensification is one of the quickest and simplest ways to apply PI to a new or existing process. In the N-1 perfusion high inoculum fed-batch process, the production bioreactor is seeded with a higher number of cells. This reduces the time needed to reach the desired cell densities for protein production or delivers a higher titer within the same time scale as standard fed-batch culture.

3 In concentrated fed-batch processes, media (consisting of production medium and feed medium) is continuously refreshed by adding it to the perfusion bioreactor. Using a retention device, spent media passes through and goes to waste. Cells and the protein product are recirculated and returned to the bioreactor. The media feed is continuous, but the protein of interest is harvested only at the end of the culture process.

4 In perfusion processes, media is circulated through a growing culture, supplying nutrients, removing waste, and harvesting the product in a single operation. The entire medium volume is exchanged daily while retaining the cells and minimizing waste, increasing cell density, longevity, and protein production. Combined production and feed media are needed to provide sufficient nutrients for high cell densities.

Media Management and PI

Optimally formulated media is the foundation of productive cell cultures. Media required for different process steps contains a unique balance of components contributing to cell growth and protein production.

Managing the media requirements of upstream processes can be challenging and represents a significant barrier to PI implementation in bioprocessing facilities. PI increases the demand, handling, management, and disposal of cell culture media, and might require additional equipment and consumables. Moreover, different PI strategies could require changes to the media formulation itself: both feed and basal media could vary depending on the intensification scenario adopted.

Before applying PI to upstream processing, the media and buffer requirements, impact on operations, and expected output must be determined for each proposed scenario. These analyses should examine how media is prepared and managed, how and when bioreactors are fed, and how waste is handled. It is important to consider the facility design; is there enough space to store additional media, is there the capacity to change existing instruments and adopt new platforms? These trade-offs will dictate which PI route biotherapeutic manufacturers might take.

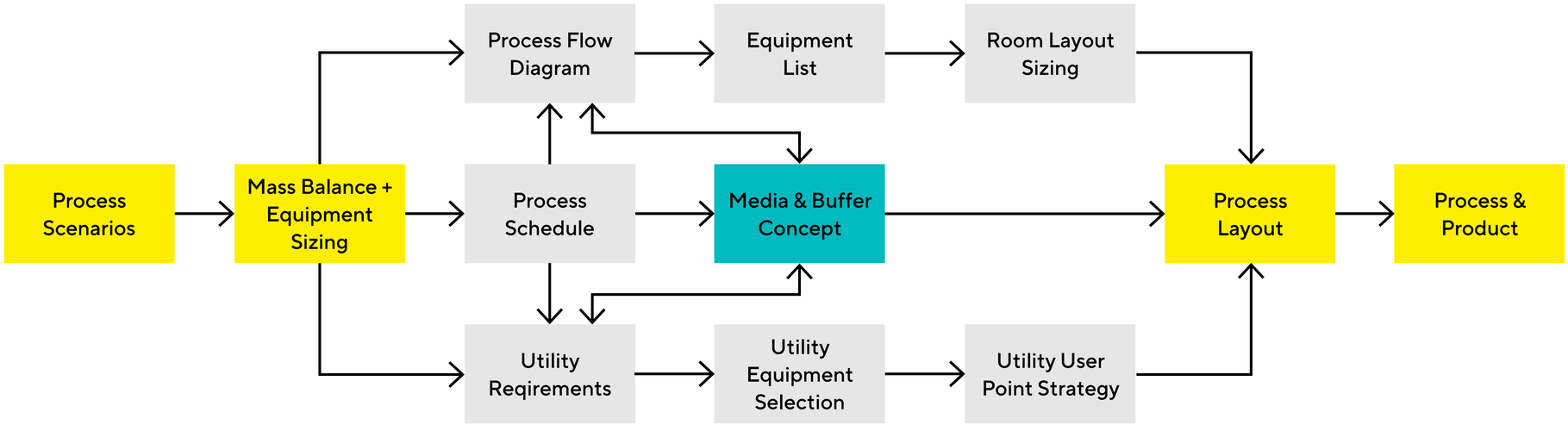
Sartorius is equipped with industry-leading experience in implementing robust PI solutions across bioprocessing applications. In this ebook, we provide support to biopharmaceutical developers who are curious about exploring PI in their upstream processes but apprehensive about managing the associated increases in media and buffer consumption. We begin by giving an overview of process design solutions and the media journey before offering insights into which PI strategies might be the most suitable and realistic for adoption in clinical | commercial manufacturing across different scenarios.

Conceptual Design – Beginning With the Final Goal

Modeling a scaled-up process and then reverse-engineering the design is the easiest method to simplify decision-making when selecting the optimal media management technique. The final process should be sculpted by the molecule type, demand, and intended throughput. Next, the strategy should be worked back to smaller scales to answer critical questions (such as how much media is required per batch), and solutions should be developed around these issues. This ensures that clinical | commercial manufacturing bottlenecks related to media management are promptly identified at an early stage.

Considerations for the process and desired outcomes will include footprint, costs, throughput, technology choice, and operations. Two important considerations include clean room space, which is a significant factor in terms of maintenance and energy costs, and water consumption, which increases with rising media requirements, leading to higher process mass intensity (PMI) and reduced process sustainability.

Managing expectations around these factors can kick-start the PI exploration process and drive developers to re-evaluate their intensification options in upstream processing. However, designing and engineering a facility according to each of these parameters can be challenging. Conceptual design tools such as the Process4Success® Platform (P4S®), from Sartorius, can provide valuable guidance during the initial stages of process development.



P4S®, a tool developed by Sartorius, evaluates PI options for specific applications and determines the implications for footprint, process workflow, and technology, considering the desired throughput and scale of the operation (Figure 2).

Theoretical modeling facilitates a process-centric approach, generating robust facility designs and processes using mass balance calculations. These outcomes lay the foundations for reliable decision-making, enabling the selection of optimal technologies and simplifying overall logistics. Processing steps are defined in the context of the unit operations, and the facility design and process workflow is generated according to related requirements such as scheduling, media preparation, and distribution (Kumar et al., 2018).

Mass balance results can determine the media and buffer requirements for each unit operation and batch, which (along with process scheduling) shapes the media concept. The media concept includes defining the number and size of the preparation (mixing) and holding tanks, and the transfer strategy, which could involve single-use tubing via a wall connection or moved through the corridor until the point of use.

This decision is highly dependent on the media volume calculated, which will define the holding tank as fixed or movable through the facility.

Together, mass balance calculations, media buffer concept, and process scheduling can create a concrete foundation for the optimal process solution and facility design.
The insights delivered by conceptual design tools remove many uncertainties surrounding the adoption of PI and the associated investment, providing opportunities to streamline processing by optimizing facility layout and manufacturing strategies.

Figure 2
The Process4Success® Platform (P4S®) is used to create different scenarios to determine procedural requirements, technology needs, and equipment sizing for each process. These outcomes are applied to scheduling and the media | buffer preparation and distribution strategy, which function interdependently with the process flow and utility requirements. Together, these iterations create the optimal facility solutions for each PI scenario.

Media Journey

In the production of biologics, cells are cultured in distinct media compositions at each stage of the manufacturing process. Typically, media is optimized for rapid expansion (seed train) or protein production.

Media for seed train (i.e., for the inoculum), adaptation, and banking is an enriched basal medium optimized for cell proliferation. Production media is formulated to encourage cells to produce proteins. It sustains cell growth and productivity and is used in batch cultures. In fed-batch cultures, production media is supplemented with feed media, which contains additives that facilitate the maintenance of cell cultures capable of high-quality protein production over longer periods.

From Prep to Use

The media journey is outlined in Figure 3.

1. Media Formulation

The first step is to determine the media's formulation, which includes the constituent amino acids, sugars, peptides, and growth factors. The final formula is dictated by the cell type, desired product, and production step.

Manufacturers must also decide how to obtain their media. Dry (powder) formulations will have a longer shelf life but require additional handling; liquid media is often missing components to extend its shelf life. Ready-to-use media might represent the easiest method but will incur greater costs and have less stable formulas.

2. Media Preparation

The next step is media preparation. The final formulation is combined, mixed, and adjusted in a closed container (such as the Flexsafe® Pro Mixer), filtered, and transferred to the media hold container. Managing the preparation of different formulations for each production stage could be challenging, as each will have its own standard operating procedures and quality control requirements. Non-efficient scheduling can lead to media exceeding its maximum storage time or shelf-life. If ready-to-use media is purchased, this is where it enters the media journey.

3. Storage | Transfer to Bioreactor

The prepared media is now ready for use and is either stored or directly transferred to the culture vessel. The frequency and volume of media introduction to the bioreactor depend on the media shelf life, stage of the process, and the bioreactor mode (fed-batch, perfusion, or concentrated fed-batch), highlighting a critical challenge – the task of scheduling the preparation of media according to the needs of the production process. It is critical the developers can prepare and store the volume of media required for use in the right place and at the right time. Optimizing these tasks is essential to ensure the process is efficient and equipment use is maximized (Figure 4).

4. Carryover to Downstream Processing

The media journey does not stop here; it carries over to the downstream process in the form of spent media or clarified broth. Media is also used in the continuous harvest of proteins.

Typical Media Journey

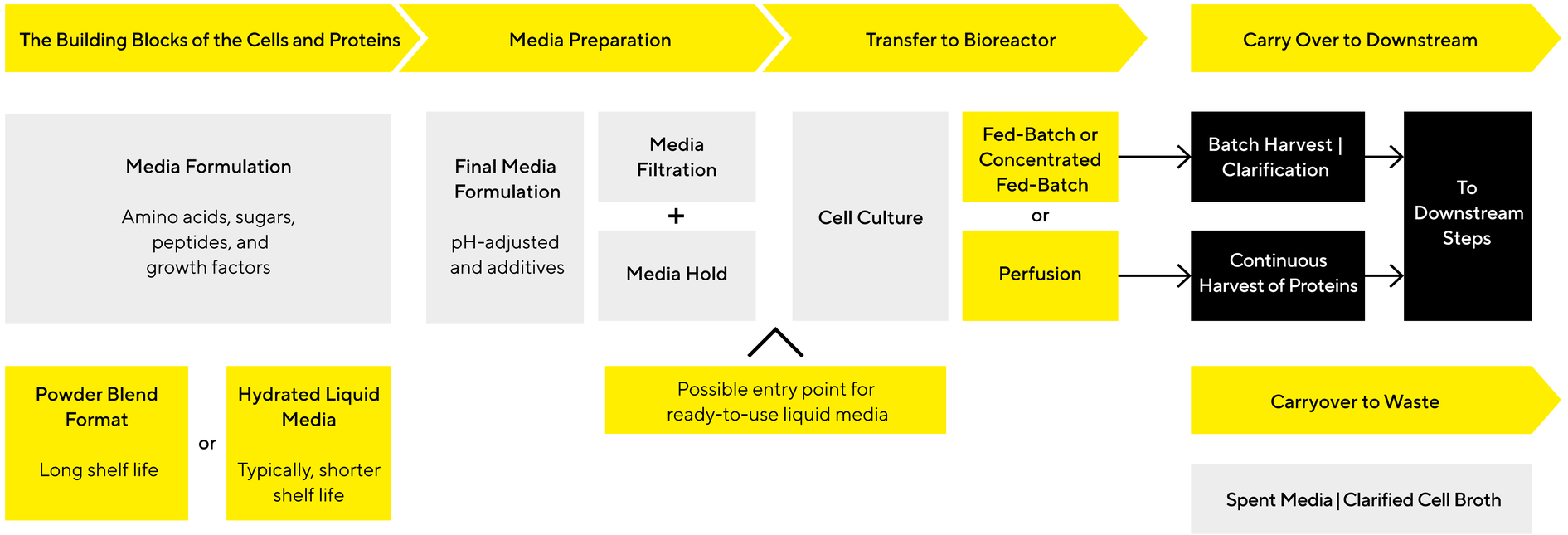


Figure 3
The process of media creation and use typically involves formulation, preparation, transfer to the culture system, and carry over to downstream.

Media Journey – Challenges in Intensified Processes

Efficient protein production during intensified upstream processing requires the reliable preparation and management of consistently high-quality media. While the concept of the media journey seems straightforward, there are a variety of obstacles to effective media management. Challenges include the simple problem of logistics: moving large volumes of liquid and fixed tanks for use throughout the process. The media management network is also influenced by the duration of media hold and its shelf life: what is the facility's storage capacity? Another issue is maintaining media quality and sterility, which relies on avoiding handling errors, instrument failure, and contamination.

Each PI approach involves different cell seeding and feeding programs (Figure 1), requiring careful consideration of the accompanying media management strategy. Compared to standard fed-batch, PI has a higher (N-1 perfusion) or significantly higher (concentrated fed-batch and dynamic perfusion) media requirement.

Before deciding on a PI strategy, biopharmaceutical manufacturers should consider the best equipment and platforms to use in their media management, keeping their capacity, production parameters, and distribution needs in mind (Figure 4). Consumables and equipment to handle the increased media volumes associated with PI are essential to support a smooth process flow, while reliable filters to avoid contamination and remove mycoplasma are critical for successful intensified processes.

One major factor in deciding how PI might be implemented and establishing an effective media management route is whether the production facility is already in place or whether a new facility is to be constructed to fit the new, intensified process.

Media and Buffer Preparation & Distribution Scenarios

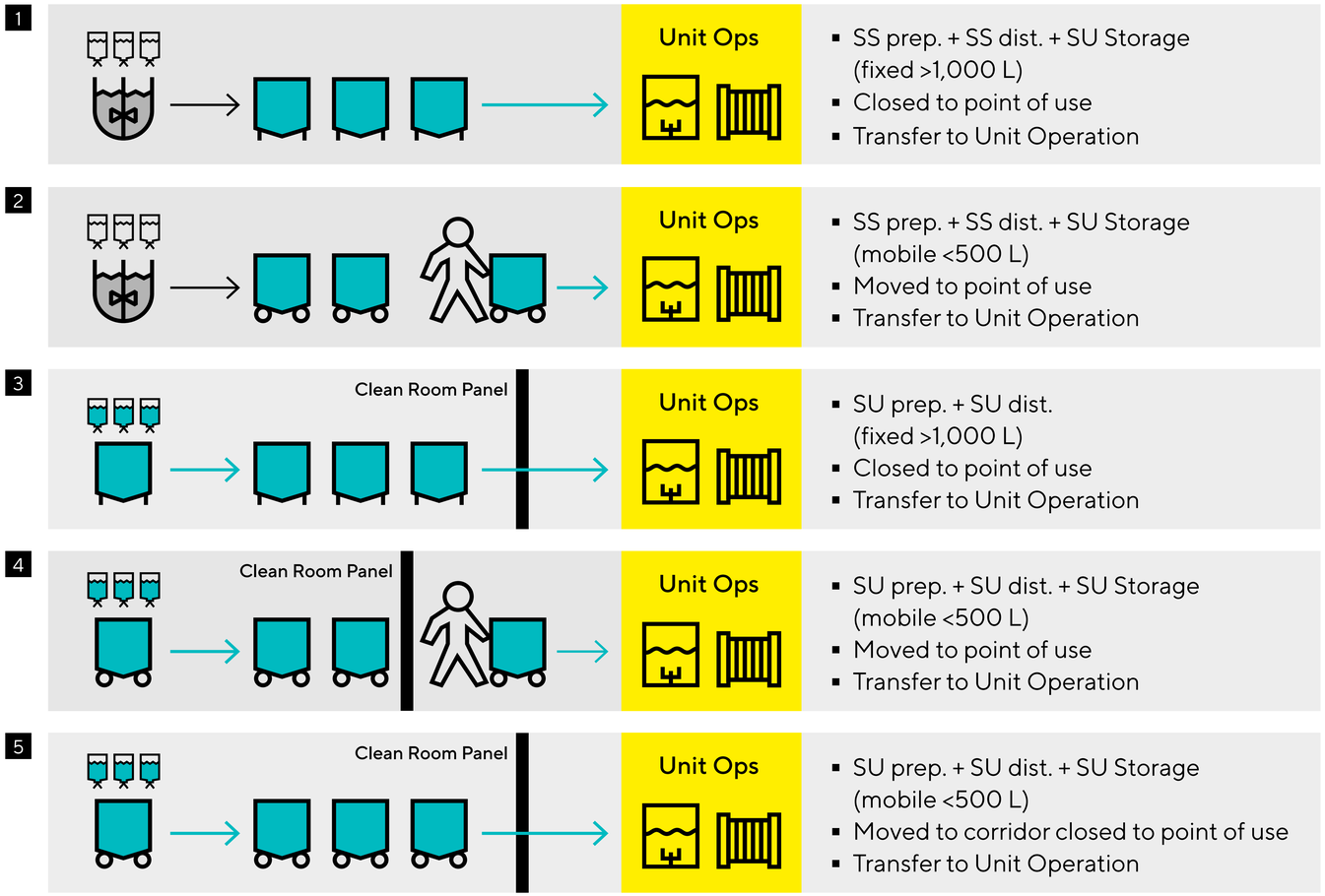


Figure 4

1 Stainless steel (SS) preparation system, fixed position for transfer to unit operation.

2 SS preparation system, mobile storage for transfer to unit operation.

3 Single-use (SU) preparation and distribution with fixed hold for large volume, media is transferred through the wall.

4 SU preparation and distribution for lower volumes; media is moved to the point of use in mobile tanks.

5 SU preparation and distribution for lower volumes; media is transferred via movable tanks to be placed in the corridor (closed to the point of use). Transfer media is via wall-through.

Addressing Media Management Strategies for PI – Existing Facilities

The ideal scenario for establishing an intensified process is to fit the facility around the process rather than to fit the process in the facility. However, this is often not possible, and flexible solutions are required to facilitate the seamless integration of PI into existing facilities with minimum disruptions. The aim is to create positive changes that provide higher productivity without the risks and implications of increased footprint, capital expenditure, and operative costs.

Seed train intensification could be an excellent opportunity to adopt intensification in an established facility where significant modifications are unrealistic. N-1 perfusion involves minimal changes to the established infrastructure and relies on existing equipment. N-1 perfusion also offers flexibility in both up and downstream processing and only requires a moderate increase (53%) in media consumption compared to fed-batch production (Figure 6a), meaning media management and logistics are unlikely to change significantly.

N-1 perfusion is still capable of enabling high throughput manufacturing with these relatively minor adjustments, achieving around a 60% increase in productivity and facility throughput with an <10% increase in the footprint associated with the upstream process | media prep area (Figure 6a). Accordingly, the risks related to increased capital investments and operating costs are significantly reduced.

Implementing dynamic perfusion and concentrated fed-batch intensification strategies in existing facilities would require more significant expenditure and retrofitting (Figure 6).

Space and cost hurdles might limit the ability to install new equipment and redesign the process to facilitate intensification strategies. There is also likely to be a substantial impact on business operations while modifications are taking place, which might not be feasible for new or smaller biotechs.

However, PI could be explored in parallel with changes to business operations. For example, concentrated fed-batch culture can facilitate the shift from stainless steel to single-use for multi-product facilities and high throughput processes, as it delivers up to a three-fold increase in production titers.

Media Management and Footprint Implications

		Basal Media Requirements [L] / Batch						Overall Achievable Throughput		
Scenario	Scale	N-1	Production Bioreactor	Media Consumption [%]	Media Consumed | Kg of DS [L/Kg]	Cell Culture Duration [days]	Titer / Batch [g/L]	DS Quantity [Yield = 70%]	Annual [kg / Yr]	Facility Footprint
1: Classical	Production 2,000 L*	500	1,360	Baseline	266 (Baseline)	12	5	7	840**	Baseline
2: (N-1) HIFB		1,500	1,360	+53%	255 (-4%)	10	8	11.2	1344 (1.6×)**	<10%
3: Concentrated Fed-Batch (CFB)		500	27,900	+1,400%	1352 (+508%)	14	15	21	1680 (2×)***	+25%
4: Dynamic Perfusion*****		500	18,900	+950%	970 (+364%)	19	28.5	20	272****	-45%

+ Quantity per batch refers to the quantity of final drug substance (DS) produced assuming process yield of 70%
* Dynamic Perfusion is carried out with 1,000 L bioreactor at production scale
** for Classical and n-1 HIFB, the USP line in the facility has 6× 2k L Production Bioreactors leading to 1 DSP line.
*** for concentrated fed-batch, the USP line in the facility has 4× 2k L Production Bioreactors leading to 1 DSP line.
**** for dynamic perfusion, the USP line in the facility has 1× 1k L Production Bioreactor leading to 1 DSP line
***** Comparison of DB Vs Classical FB (2×2k L) to achieve similar annual throughput

Figure 5
Media management and footprint implications for different upstream process intensification scenarios at manufacturing scale.

Addressing Media Management Strategies for PI – New Facilities

Designing a new biopharmaceutical facility is influenced by a range of drivers, including the need to meet regulatory requirements, supporting a sufficient production capacity for the product in mind, and the flexibility to adapt to changing demands. Biopharmaceutical developers maximize their intensification opportunities when they consider how PI could be applied during the early stages of design and conceptual modeling of a new facility.

To capitalize on the potential for increased product output, establishing upstream processing with either a concentrated fed-batch or dynamic perfusion strategy is desirable. However, media is constantly exchanged in these processes, posing a greater challenge for media preparation, management, and feed scheduling.

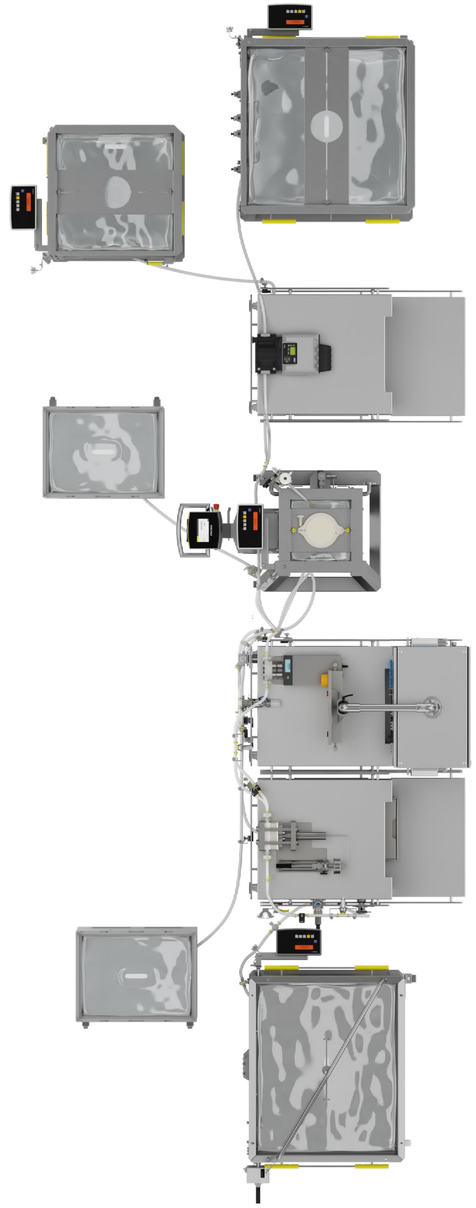
Concentrated fed-batch culture offers flexibility in the production process and can facilitate a three-fold increase in production titers (Figure 5). A concentrated fed-batch process would be more appropriate where the facility throughput or drug demand is high. It also has high media requirements, consuming approximately 1,400% more than a corresponding fed-batch process (Figure 5).

Concentrated fed-batch culture could be an attractive strategy for achieving a significantly higher throughput with an existing single-use facility to meet higher drug demands. It could also be implemented to support conversion from stainless steel to single-use solutions to save on footprint, investment, and running costs when manufacturing drugs at scales more than 1.5 tonnes per year.

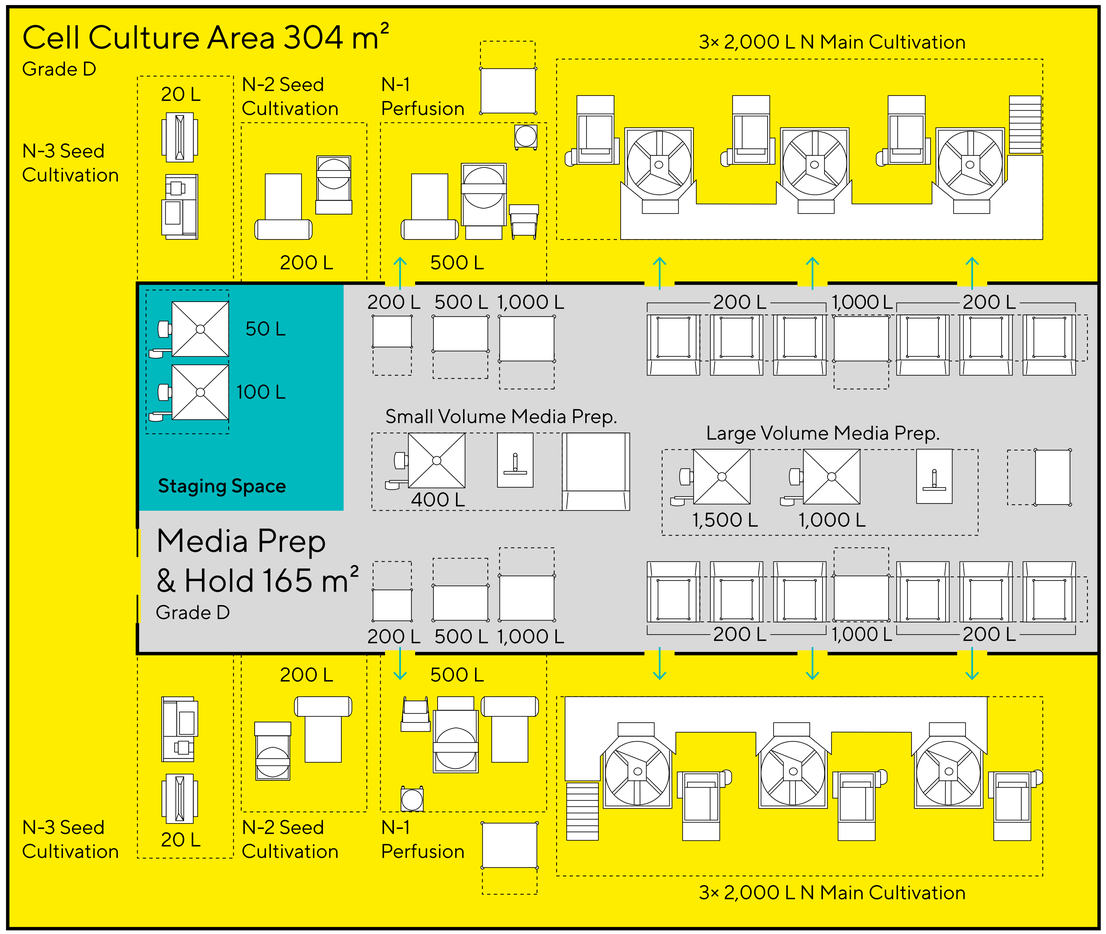
Dynamic perfusion is a flexible strategy and can deliver a significant increase in productivity (up to 5× compared to fed-batch) (Figure 5).

Dynamic perfusion approaches are recommended where drug demand and facility throughput are low and there is a lower risk due to minimal upfront investment. As demand for the product increases, production capacity can be increased by scaling out regionally or globally. Dynamic perfusion is also particularly valuable in the manufacture of difficult-to-express molecules due to their low stability, which is tricky to manage in standard fed-batch production.

Process intensification by dynamic perfusion requires limited equipment and installation costs to begin production in new facilities, as it represents an effective bridge from process development to pilot (and eventually commercial) production. However, it has an extremely high media requirement, approximately 1,000% greater than an equivalent fed-batch production process (Figure 6b).



Facility Footprint Study for N-1 Perfusion Scenario



Legend

- Wall through liquid transfer
- Blocked Handling Area
- Balance
- Palletank® Storage
- Biostat STR®
- ATF Module
- Stairs
- FA 3,0 B Flexact® Modular MP
- Biostat® RM
- Palletank Mixing Weighing
- CFB — 2× 2,000 L Concentrated Fed-Batch

Figure 6a
The design represents an easy retrofit of an existing facility using standard fed-batch culture to an N-1 perfusion scenario, where 6× 2k L cultivation and N-1 perfusion at 500 L scale are carried out. Both small and large media prep volumes and wall through transfer via single-us (SU) storage tanks to the unit ops is also represented.

Facility Footprint Study for Dynamic Perfusion Scenario

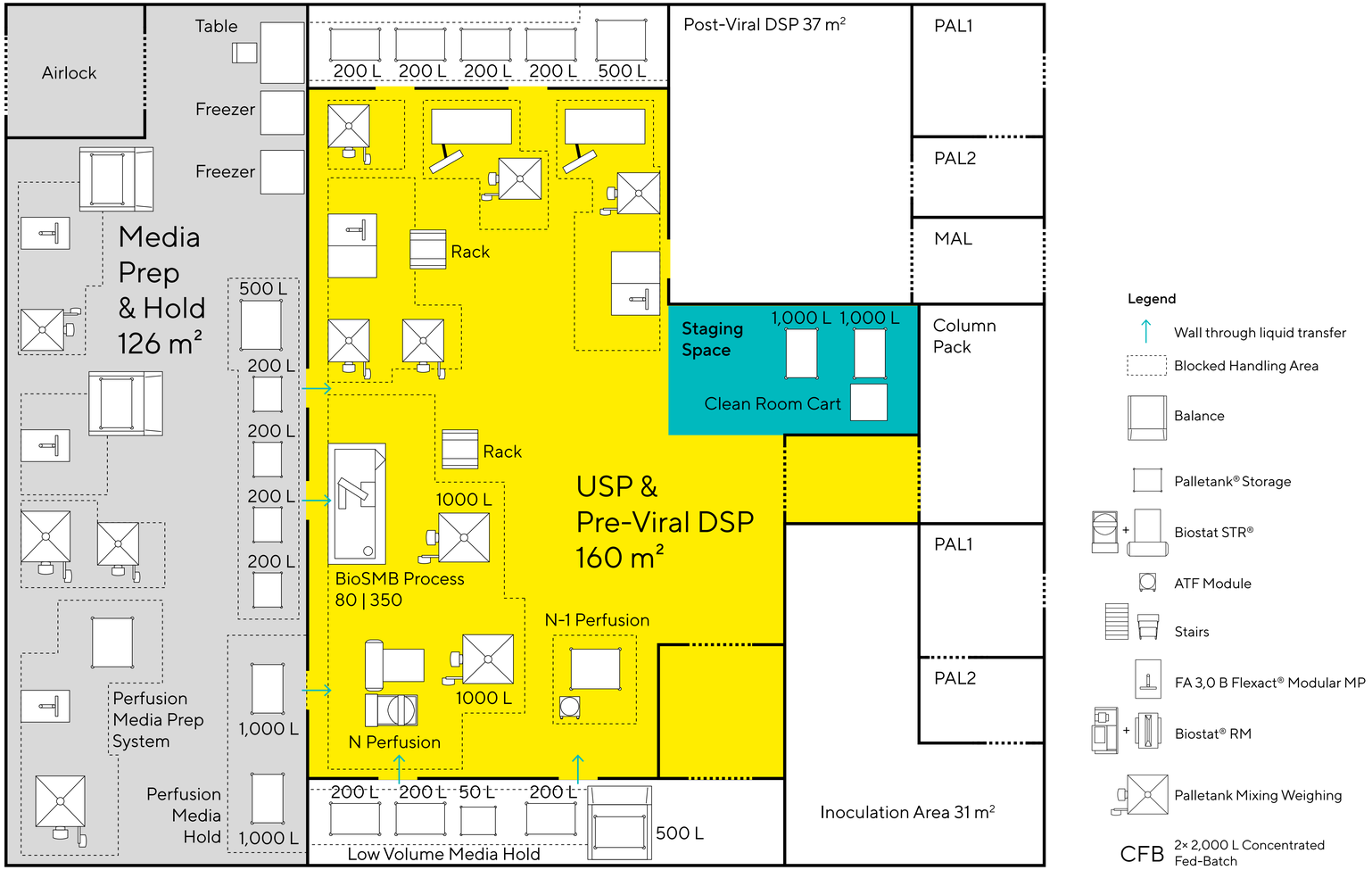
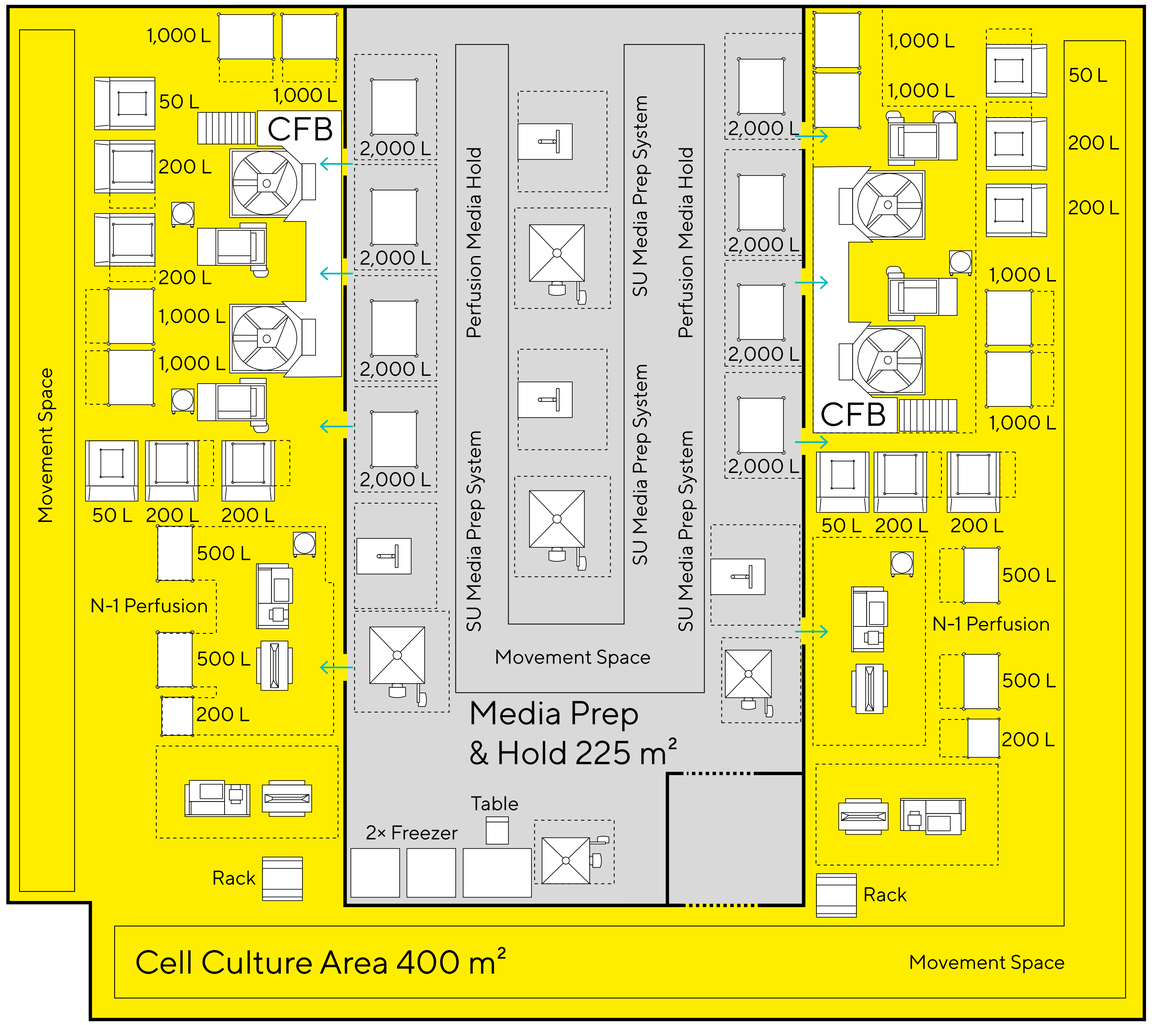


Figure 6b
A large volume of perfusion media requires transfer from media prep | hold room to the upstream processing (USP) room via single-use (SU) tubing.
A low volume of media stored in movable tanks is situated in the corridor and supplied via SU tubing wall to wall.

Facility Layout Study for Concentrated Fed-Batch Scenario



Legend

- Wall through liquid transfer
- Blocked Handling Area
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- Biostat® RM
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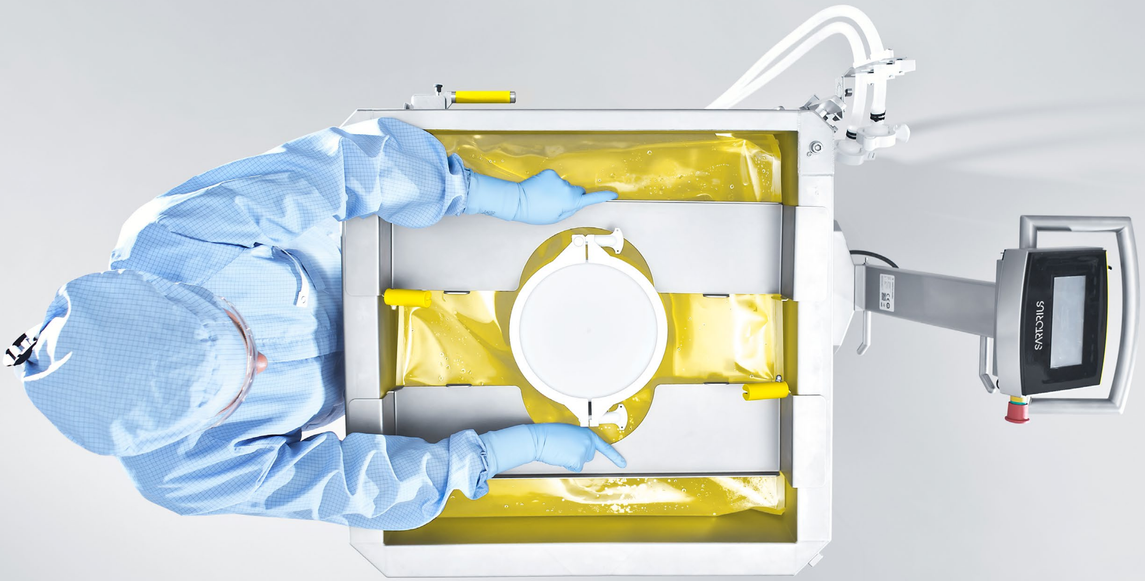
- CFB — 2× 2,000 L Concentrated Fed-Batch

Figure 6c
4× 2k L cultivation requires 4× FlexAct (FA) systems for media prep (3× FA dedicated for preparation for perfusion media). 2× 2k L single-use media hold tanks are required to store and distribute perfusion media per bioreactor.



Preparation and Hold

Figure 7 summarizes our recommended media management strategy according to each PI scenario. Since media use in both concentrated fed-batch culture and dynamic perfusion is significant, media preparation will have to be carefully scheduled to ensure a consistent and timely media supply.

If preparation must follow a tight schedule, media does not need to be held in the facility and can instead be directly transferred to the bioreactor. However, operations might run more smoothly if media is prepared and mixed in advance, requiring the space and consumables to hold it. Cells cannot be without the nutrients in media, so delays to media preparation are not an option.

Concentrated fed-batch production delivers a two-fold increase in facility throughput with a 1,400% increase in media consumption and a net increase in the footprint of 25% (Figure 6c).

At this scale, single-use technologies can still be employed (Figure 7). This assessment is based on a facility with four 2,000 L bioreactors operated in concentrated fed-batch mode and might not hold true for other setups. The addition of further production bioreactors would facilitate the need for stainless steel tanks or other alternative approaches. However, we believe that there is a minimal need to move towards stainless steel technologies for media management, as throughputs of an estimated 1,700 kg per year can already be achieved with a fully single-use approach for concentrated fed-batch production, which would fulfill the demands of most of the market.

Intensification by dynamic perfusion cuts the facility footprint in half (Figure 7) with an approximately 1,000% increase in media consumption compared to a two 2,000 L bioreactor fed-batch process that would provide the same throughput (Figure 6). Media management can still be carried out using single-use technologies, as outlined in Figure 7.

Media Management Strategies at Manufacturing Scale for Each PI Scenario

Bioreactor: N-1	For Basal Media						
Scenario	Bio-reactor Volume [L]	Media Requirements / Batch [L]	Media Prep Tank Size [L]	Number of Preps Required	Frequency of Preps	Size of Hold Tank [L]	Number of Hold Tanks Required
Standard FB	500	500	650	1	1/batch	500	1
N-1 HIFB	500	1,500	1,500	1	1/batch	1,000 and 500	1 each
CFB*	100	500	650	1	1/batch	500	1
Dynamic Perfusion*	100	500	650	1	1/batch	500	1

Bioreactor: N	For Basal Media						
Scenario	Bio-reactor Volume [L]	Media Requirements / Batch [L]	Media Prep Tank Size [L]	Number of Preps Required	Frequency of Preps	Size of Hold Tank [L]	Number of Hold Tanks Required
Standard FB	2,000	1,360	2,000	1	1/batch	1,000 and 500	1 each
N-1 HIFB	2,000	1,360	1,500 or 2,000	1	1/batch	1,000 and 500	1 each
CFB*	2,000	27,900	2,000	14	14/batch	2,000	2
Dynamic Perfusion*	1,000	18,900	2,000	10	10/batch	1,000	3

*For CFB and Dynamic Perfusion, N-1 step is carried out in a perfusion mode

Figure 7
Recommended media preparation & hold strategy for the different upstream scenarios at manufacturing scale.

Logistics

As well as preparation and scheduling, the logistics of media movement throughout the process is also a critical factor in facility design and PI strategy. Considerations include the type and the volume of the media, how it is to be stored and trafficked, and the cut-off point for single-use technologies (Figure 4).

Navigating the feeding, transport, and layout needs for media in each scenario will ultimately shape the PI strategy. It is essential that the logistics are streamlined, and the facility is designed such that manufacturers can reliably prepare, store, and distribute the required volume of media at the correct times (Figure 6). This extends to bioreactor feeding strategies, outlined in Figure 4.

Waste

The media journey does not end when it enters the bioreactor. An important consideration in safe biopharmaceutical manufacturing is the spent media volume in the waste (concentrated fed-batch) or post-capture (dynamic perfusion). This spent media needs to be efficiently decontaminated in kill tanks to be compliant with environmental regulatory guidance. The increased volumes in intensified upstream processing have critical implications for waste management, including sustainability and footprint.

Media Management – Next Steps

Opportunities

Media Concentrates

The resources required for the preparation, storage, and distribution of large media volumes can be significant. Media concentrates are created by separating the low solubility components from the media cocktail, enabling further concentration of the media. Utilizing media concentrates offers an opportunity to streamline the early steps of the media journey, reduce the space and operational footprint, and enhance flexibility. Media concentrates require dilution before final use, which can be achieved via in-line dilution.

In in-line dilution, a core set of stock solutions in concentrated form are used as a basis for all media and buffer requirements; these stock solutions can be diluted, mixed, and adjusted to create process media. This method significantly limits the facility footprint but can be complex to schedule and handle. In-line dilution requires the creation of a concentrated version of each final buffer, which is diluted and adjusted as necessary. Compared to in-line conditioning, this approach requires a larger storage footprint but facilitates simpler media management. Media concentrates offer an opportunity for facilities to explore more PI options by minimizing storage needs. The same principles can be applied to buffer management in downstream processing to extend these opportunities. However, their application will require adjustments to the preparation and feeding strategy to accommodate the separation of the media | buffer materials.

Outsourcing

Current trends towards decentralization in the biopharmaceutical industry are driving more developers to consider outsourcing their media and buffer production. Taking advantage of the resources offered by an external partner drastically reduces footprint and capital expenditure, placing emphasis on quality and reliability. It could represent an attractive alternative or supplementary approach to existing media preparation strategies, enabling facilities to meet higher media requirements, increase the supply chain robustness, and respond quickly to process and demand changes.

Conclusion

Choosing to implement PI is likely to impact the setup and operation of your facility significantly. When evaluating intensification options, it is critical to consider each scenario's influence on all aspects of your process, as this information may change which option is best suited to your organizational needs. Despite representing an essential branch of decision-making, media management is an often-overlooked topic. We hope this guide demonstrates the importance of media in the successful adoption of PI and supports the effective selection of intensification strategies across a range of bioprocessing contexts. Ultimately, the decision-making process can be simplified by considering the end goals of production, including the features of the biotherapeutic, scale of manufacturing, and the potential for change in the facility. By managing the risks involved early in development and understanding production requirements, the best PI scenario can be implemented without compromising the benefits it brings to the table. Conceptual design with careful consideration of these factors will set drug manufacturers on the right path to implementing the best PI scenario for their processes.

Author Bios

Stuart Tindal
PhD, Product Manager.
Flexact Platform, Sartorius

Stuart is responsible for managing Sartorius' automated single-use downstream and liquid processing platform. He is an organic chemist come biochemical process engineer, and process analytical technology subject matter expert for the bioprocess industry. Originally from Scotland, he currently resides in Göttingen, Germany.

Stuart has worked in the technical and commercial field of bioprocess technology for the past 15 years. He gained ten years' technical marketing experience in single-use automation | sensors and process analytical technologies while working as a Product Manager for Sartorius. Before that, he carried out biochemical engineering doctorate training and worked as a process development scientist.

Basak Kochan
MS, Process Consultant - Advanced Engineering, Sartorius

Basak is responsible for executing conceptual design projects within the Advanced Engineering team at Sartorius. She has a process engineering background in the bioprocess field. Originally from Turkey, she has been living in Germany for nearly seven years.

In her current role, Basak leads various conceptual design, feasibility checks, front-end projects for the best process and layout solutions, considering the business and process needs of her customers. She also developed a process modeling tool under the P4S® Platform to create solid foundations for technology integration and equipment arrangement in a facility layout design.

Ganesh Kumar
MS, Market Entry Strategy Manager - Protein-Based Therapies, Sartorius

As part of the Protein-Based Therapies team at Sartorius, Ganesh collaborates with clients and business areas on process positioning, building the technical platform, and solution packages for process intensification. He has over eight years experience in the biopharmaceutical industry, both as an end-user and a solution provider. He is based in Göttingen, Germany.

Ganesh started his career at Lonza, Singapore, where he was actively involved in the tech transfer, validation, and large-scale commercial manufacturing of blockbuster mAbs. Ganesh joined Sartorius in 2016 as a Process Engineer | Consultant and was one of the key contributors to the development of the P4S® conceptual design platform.

Katy McLaughlin
PhD, Scientific Content Writer, Sartorius

Katy is part of the Marketing Communications team at Sartorius, where she supports the creation of a variety of written pieces, from published articles to web content.

Before joining Sartorius in 2021, Katy was employed as a Post-Doctoral Research Associate at the University of Edinburgh, where she also completed her doctoral studies. Here, she carried out research in genetics and cellular biology and began taking on writing projects, eventually entering into a career as a freelance writer for various biotech companies and agencies.

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Germany
Sartorius Stedim Biotech GmbH
August-Spindler-Strasse 11
37079 Goettingen
Phone +49 551 308 0

USA
Sartorius Stedim North America Inc.
565 Johnson Avenue
Bohemia, NY 11716
Toll-Free +1 800 368 7178

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www.sartorius.com/process-intensification

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