Review Article

Refurbishment of CG Membranes in GMP Isolators: A Cost-Saving, Sustainable Strategy for Aseptic Pharmaceutical Manufacturing

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ABSTRACT

In isolator-based aseptic pharmaceutical manufacturing, maintaining a Grade A environment is essential to ensure product sterility and regulatory compliance. A critical component in preserving this controlled environment is the CG (Ciba Geigy) membrane or distributor, which plays a key role in sustaining uniform, unidirectional airflow within the isolator. Traditionally, when these membranes show signs of wear, contamination, or material degradation, facilities rely on full replacements from OEM suppliers, a process that typically involves lead times of 10–12 weeks and significant cost. In one instance, the replacement of 10 membranes was quoted at over $110,000 USD. This case study explores a practical and cost-effective alternative: the refurbishment of existing CG membranes. Applied to a commercial-scale sterile vial filling isolator, the refurbishment process followed a validated protocol that included material integrity checks, cleaning, reconditioning, and final qualification testing such as pressure decay and airflow uniformity assessments. The results were compelling. The refurbished membranes matched OEM performance in terms of airflow consistency, leakage integrity, and pressure retention. The total refurbishment cost was reduced to approximately $50,000—yielding a savings of more than 55%. Beyond financial benefits, this initiative also helped reduce environmental waste and minimized reliance on single-source suppliers. These findings support CG membrane refurbishment as a viable, GMP-compliant strategy for pharmaceutical manufacturers seeking to improve operational efficiency, reduce maintenance costs, and advance sustainability goals. The approach provides a scalable, repeatable model for other facilities aiming to optimize isolator performance without compromising quality or compliance.

Keywords: Aseptic manufacturing, Isolator systems, Ciba Geigy distributor, Laminar airflow, Component refurbishment, pharmaceutical sustainability, Equipment lifecycle management.

INTRODUCTION

In aseptic pharmaceutical manufacturing, isolator systems have become the industry standard for creating sterile environments critical to drug product safety and compliance. These systems are designed to maintain a Grade A (ISO Class 5) environment, where even minor airflow deviations or containment breaches can compromise product sterility, potentially leading to costly deviations or recalls[1,17]. According to FDA guidance, maintaining cleanroom standards using HEPA-filtered laminar airflow is essential for aseptic processing operations[1], and this is echoed across international standards such as ISO 14644-5[4] and Annex 1 of EudraLex Volume 4[11].

A key internal component in such isolator systems is the CG (Ciba Geigy) membrane, often referred to as the airflow distributor. This membrane is positioned in the ceiling plenum and plays a vital role in dispersing clean air uniformly across the Grade A zone[8,16]. Its function supports the establishment of consistent unidirectional laminar flow, which minimizes turbulence and ensures contaminants are swept away from critical areas, in line with Good Manufacturing Practice (GMP) principles[6,14].

However, CG membranes are not immune to wear. Prolonged exposure to hydrogen peroxide vapor, cleaning agents, thermal cycles, and particulate load during operations can cause them to degrade or deform[20,29]. This degradation can distort airflow patterns or compromise airflow integrity, putting aseptic conditions at risk. As a result, most pharmaceutical manufacturers replace these membranes as part of routine preventative maintenance[3,19].

Yet replacements are costly and slow. In the case described in this paper, the OEM quoted over $110,000 USD for 10 replacement membranes, with delivery lead times of 10–12 weeks from a European supplier[2]. Such timelines can severely affect production schedules, particularly for high-throughput sterile manufacturing lines. More broadly, these long lead times and costs highlight a growing vulnerability in supply chain dependence, especially in post-pandemic operations where resiliency and sustainability are key manufacturing priorities[10,18].

Despite the membrane's significance, limited peer-reviewed literature exists on refurbishment or lifecycle extension of such components. The industry norm remains focused on replacement, often without exploring whether performance-equivalent refurbishment could offer cost-effective, GMP-compliant alternatives. Meanwhile, other sectors of healthcare and pharmaceutical production—such as remanufactured surgical devices and repurposed isolator glassware—have demonstrated validated reuse strategies that resulted in significant cost savings and environmental benefits[21,24].

This paper addresses that knowledge gap by presenting a case study from a commercial aseptic vial filling isolator, where a complete set of CG membranes was refurbished instead of replaced. The study evaluates the refurbishment method, technical validation steps (e.g., surface tension, airflow velocity, pressure hold), and final outcomes, comparing the results against OEM specifications. It aims to demonstrate that membrane refurbishment can be a feasible, scalable, and sustainable approach for pharmaceutical manufacturers operating under strict GMP requirements[7,25].

1. Literature Review:

Maintaining unidirectional, particle-free airflow within aseptic isolators is foundational to modern sterile pharmaceutical manufacturing. Regulatory agencies such as the U.S. FDA[1,17] and international organizations like ISO[4] have codified the necessity of achieving ISO Class 5 (Grade A) cleanroom standards in environments where sterile drug products are produced. These conditions are typically maintained using isolators with HEPA-filtered laminar airflow, which direct clean air over critical zones to minimize the risk of microbial and particulate contamination[6,8,16].

Isolator design and validation protocols have been extensively studied. Visual airflow visualization (smoke studies), air velocity measurements, pressure decay testing, and decontamination cycle development are recognized validation techniques required by both the FDA and PIC/S[6,11,12,24]. Pharmaceutical isolators are widely used in vial filling lines, sterility testing chambers, and lyophilization units, and are often preferred over cleanrooms and RABS due to their superior containment and sterility assurance[3,18,26].

However, while extensive research exists on isolator airflow dynamics, pressure decay testing, and environmental monitoring, little published data is available on the maintenance or lifecycle extension of internal components—especially airflow distributor membranes like the CG (Ciba Geigy) membrane[3,19]. Most industry practices assume full replacement of these components after wear or airflow issues, without exploring refurbishment as a cost-effective or sustainable alternative.

In contrast, the broader field of remanufacturing in engineering and healthcare offers evidence that carefully controlled reuse of high-value components—when performed with validated cleaning, testing, and compliance protocols—can maintain functional equivalency while significantly reducing environmental waste and operational costs[10,21,24]. A study by Psarommatis & May (2025)[10] modeled sustainable product reuse and demonstrated that circular remanufacturing strategies can provide substantial cost-benefit ratios when applied within a validated framework. Similarly, other researchers have reported success in reconditioning non-product-contact components within isolators—such as glove ports, valves, and mechanical assemblies—without impacting GMP compliance[25,31].

Additionally, initiatives involving reprocessed single-use medical devices have demonstrated up to 60% reductions in CO_2 emissions and thousands of dollars in cost savings per operating room, provided strict quality control and regulatory guidelines are met[21]. These findings support the hypothesis that component refurbishment in pharmaceutical isolators could yield comparable benefits—yet this approach remains unexplored in the literature.

This study contributes to closing that gap by presenting a validated refurbishment protocol for CG membranes and demonstrating its performance parity with OEM replacements through rigorous testing of airflow, pressure retention, and cleanroom compatibility. In doing so, it lays the groundwork for further research and adoption of validated refurbishment practices in the pharmaceutical sector, aligned with both economic and sustainability goals.

2. Materials And Methods

This study was designed as a technical case study to evaluate the feasibility, performance, and regulatory suitability of refurbishing CG (Ciba Geigy) membranes used in a GMP-compliant isolator for sterile vial filling. The methodology was developed to meet current Good Manufacturing Practices (cGMP) and focused on replicating Original Equipment Manufacturer (OEM) standards through validated reconditioning procedures, followed by quantitative and qualitative performance testing.

2.1 Study Design and Setting

The refurbishment was conducted on 10 CG membranes previously installed in the ceiling plenum of a commercial isolator operating under ISO Class 5 (Grade A) environmental controls. The work took place in a designated cleanroom-adjacent maintenance area equipped for handling critical airflow components. All personnel involved were trained in cGMP protocols, and activities were documented according to internal Standard Operating Procedures (SOPs).

2.2 Refurbishment Workflow

Each membrane underwent a structured 7-step refurbishment process:

1. **Removal and Transport** – Membranes were safely removed under lockout/tagout procedures and transferred to a clean maintenance area.
2. **Visual Inspection** – Surfaces and seals were inspected for mechanical damage, contamination, or degradation.
3. **Cleaning** – Membranes were cleaned using sterile 70% isopropyl alcohol (IPA) and lint-free wipes in a controlled environment.
4. **Seal Reconditioning** – Damaged edge seals were repaired or reattached using cleanroom-compatible

adhesives and alignment tools along with PETP (polyethylene terephthalate).

5. **Surface Tension Testing** – Surface hydrophobicity was measured using a calibrated Tefas-check 100 surface tension meter. Acceptable results were defined as within 5–7 N/cm.
6. **Pressure Integrity Testing** – Pressure hold tests were performed using a sealed rig and later reconfirmed post-installation using the isolator's integrated sensors.
7. **Reinstallation and Requalification** – Membranes were reinstalled and subjected to airflow velocity measurements and smoke visualization to confirm laminar flow and overall cleanroom suitability.

All refurbishment and validation steps were logged for traceability and audit readiness.

3. Refurbishment Process

3.1 Isolator and CG Membrane Overview

The CG (Ciba Geigy) membranes assessed in this study were originally installed in a Grade A vial filling isolator operating under cGMP conditions. The isolator contains 10 CG membranes integrated into the ceiling plenum as shown in figure 1, which regulate unidirectional airflow and ensure uniform air distribution across the critical aseptic zone.

Each membrane is constructed using PETP (polyethylene terephthalate), specifically the SEFARE PETEX 07.4/25 monofilament mesh. This material is selected for its exceptional chemical resistance, dimensional stability, low particulate shedding, and compatibility with high surface tension airflow systems. PETP maintains its shape and functional integrity under repeated exposure to sterilant such as 70% IPA and vaporized hydrogen peroxide (VHP), making it ideal for use in isolators that require both mechanical durability and GMP compliance.

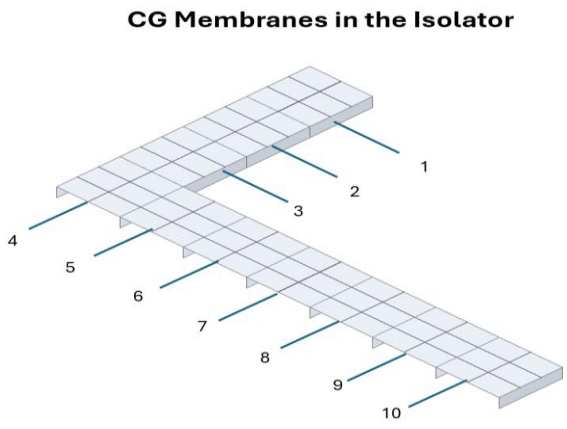

Figure 1: 10 CG membranes in the isolator

3.2 Refurbishment Procedure

The membranes were carefully removed, cleaned, inspected, and revalidated as part of a refurbishment strategy aimed at reducing cost and lead time without compromising performance. The refurbishment process followed a validated protocol consisting of:

- Visual inspection for particulate accumulation and mechanical damage
- Surface cleaning with sterile, non-reactive solvents (70% IPA) in a controlled environment
- Reconditioning and minor repair of edge seals, where applicable
- Integrity testing, including pressure retention and airflow checks.

Refurbishment was performed by a qualified third-party vendor with experience handling sterile barrier components under cleanroom-compatible conditions. All procedures followed a documented internal SOP aligned with cGMP expectations.

3.3 Surface Tension Testing

Post-refurbishment, each CG membrane underwent surface tension testing using a Tefas-check 100 tensiometer, the same device model used in original OEM qualification. The test ensures hydrophobic and laminar-flow properties of the membrane material are preserved. Acceptable surface tension was defined as 5–7 N/cm, with the device capable of measuring within a broader certified range of 3–24 N/cm. All tested membranes met the required specification.

3.4 Leak Integrity Testing

Pressure decay tests were conducted using the isolator's built-in system. Each membrane section was sealed and held at a defined pressure for 60 seconds. Alarms were triggered if pressure dropped below 1 bar. All 10 refurbished membranes passed without triggering deviation alarms, indicating satisfactory seal integrity.

3.5 Airflow Uniformity Assessment

Air velocity probes were used to verify airflow uniformity beneath the plenum post-installation. Measurements were taken at five locations per membrane to ensure consistent downward laminar flow. The results were consistent with historical OEM benchmark data. Optional smoke pattern testing was conducted during requalification to confirm proper directional flow as shown in the figure 2.

3.6 Refurbishment Procedure (Step-by-Step)

The refurbishment of the CG (Ciba Geigy) membranes was conducted on-site within a controlled cleanroom-adjacent service area, following internal procedures that adhered to cGMP principles. The goal was to restore airflow integrity and material performance without compromising isolator function or cleanliness. The entire process was carried out by trained personnel using cleanroom-compatible tools and validated materials.

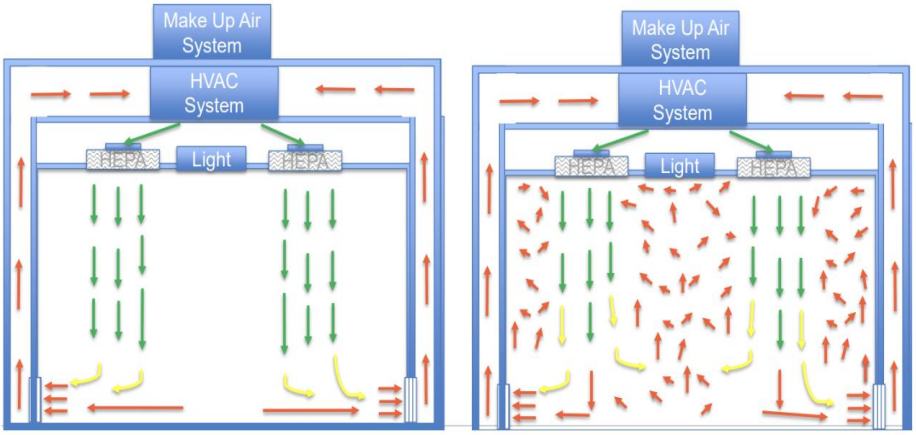

Figure 2: Left Image: Theoretical/Expected Airflow Pattern
Right Image: Empirical/Measured Airflow Pattern

Below is the step-by-step refurbishment procedure:

Step 1 Membrane Removal

- The isolator was powered down and locked out according to plant safety protocols.
- Each CG membrane panel was carefully detached from its ceiling frame to prevent tearing or misalignment.
- Removed membranes were placed in pre-cleaned stainless-steel carts and transported to the service zone.

Step 2 Initial Inspection

- A thorough visual inspection was conducted to identify:
    - Surface damage
    - Particle buildup
    - Seal separation or cracks.
- Any membranes with critical mechanical damage were set aside for rejection or partial rebuild.

Step 3 Disassembly & Cleaning

- Current PETP material is removed and dried adhesive is removed.
- Membranes were cleaned using 70% isopropyl alcohol (IPA) and sterile wipes in a low particle-controlled area.
- Special attention was given to the membrane's surface and edges where bioburden or particulate buildup is common.
- A lint-free cloth was used for final drying.

Step 4 Edge and Seal Reconditioning

- Loose or worn perimeter seals were:
    - Reattached with cleanroom-compatible adhesive.
    - Reinforced with mechanical edge trimming, if needed
- Minor dents or deformation were corrected using non-abrasive tools.
- A new PETP (polyethylene terephthalate) sheet—SEFARE PETEX 07.4/25—was applied to the membrane frame. The sheet was tightly stretched and secured to all sides using a compatible adhesive to ensure firm contact without over-application or leakage beyond the frame edges.
- Exceptional care was taken to achieve uniform surface tension and prevent sagging or ripples, which could negatively impact laminar airflow consistency.
- The membrane was then visually reinspected for flatness and alignment.

Step 5 Surface Tension Check

- Each refurbished membrane was tested using a Tefas-check 100 tensiometer.
- The surface tension was confirmed within the validated operating range of 5–7 N/cm.
- Results were logged and verified against historical OEM certificates.

Step 6 Final Integrity Test

- After refurbishment, each unit was temporarily mounted in a bench rig simulating airflow condition.
- A pressure hold test was performed to ensure:
    - No visible leakage
    - Proper pressure decay behavior over 60 seconds
- Only membranes passing this test were cleared for reinstallation.

Step 7 Reinstallation and Validation

- The refurbished membranes were reinstalled into the isolator.

- Alignment and seal placement were verified.
- The system was powered up and subjected to:
    - Full airflow uniformity testing
    - Pressure integrity validation.
    - Smoke pattern visualization (optional)

All refurbished membranes passed validation without deviations. A full record of membrane serial numbers, surface tension results, and pressure test logs was retained for internal traceability.

4. Results

This section presents the outcomes of refurbishing 10 CG (Ciba Geigy) membranes used in the ceiling plenum of a GMP-compliant vial filling isolator. All refurbished components underwent rigorous validation testing prior to reinstallation. Results were evaluated against historical OEM specifications to ensure performance equivalence and continued adherence to cGMP standards.

4.1 Surface Tension Testing

Each membrane was tested using a Tefas-check 100 surface tension meter to confirm hydrophobicity and airflow compatibility. The surface tension values for all 10 membranes fell within the validated range of 5–7 N/cm, consistent with both OEM specifications and previously supplied certificates of conformance. These results confirm that the membrane surface material retained its functional performance following refurbishment, preserving airflow dynamics, and minimizing particulate adhesion within the isolator.

4.2 Leak Integrity and Pressure Hold

Following reconditioning and prior to reinstallation, each membrane was subjected to a pressure decay test. Membranes were mounted to a sealed rig simulating isolator conditions and pressurized for a 60-second hold period. Acceptable pressure retention was defined as no drop below 1 bar during the test window.

All 10 membranes passed with no measurable pressure loss, indicating restored physical integrity and effective seal reformation. After reinstallation, system-level pressure tests were repeated using the isolator's integrated monitoring system. No deviation alarms were triggered during requalification, confirming complete containment and pressure retention.

4.3 Airflow Uniformity and Laminar Flow Integrity

Air velocity was measured using calibrated probes positioned at five standard locations across each membrane's outlet face. The resulting airflow profiles were benchmarked against historical OEM data for the same isolator configuration. Measured velocities were within ±10% of OEM baseline values, and no turbulence or irregularities were observed. Optional smoke pattern testing confirmed stable, unidirectional laminar flow across the Grade A critical zone, validating that refurbishment had no negative impact on airflow uniformity or environmental control.

4.4 Visual Inspection and Cleanroom Readiness

All membranes underwent visual inspection under bright-field lighting following cleaning and reconditioning. Surfaces were examined for wear, tears, delamination, and contamination. Edge seals and mounting frames were checked for deformation or mechanical stress. All 10 membranes met visual acceptance criteria and were deemed suitable for cleanroom re-entry.

Figure 3: OEM CG membrane

Figure 4: Refurbished CG membrane post-reconditioning. White upper and lower sheets (PETP -SEFARE PETEX 07.44/25) remain intact, ensuring airflow diffusion and structural support.

4.5 Cost Savings Analysis

Refurbishment of all 10 CG membranes was completed at a total cost of approximately $50,000 USD, inclusive of labor, cleaning, reconditioning materials, and validation testing. The OEM replacement quote for the same components was $110,000 USD, with a projected lead time of 10–12 weeks as shown in the following table 1.

This represents a 55% cost reduction, while also shortening equipment downtime and mitigating supply chain disruptions. No functional or regulatory performance trade-offs were observed.

Table 1: Cost saving analysis

Cost Category	OEM Replacement	Refurbishment	Savings
Total Material + Service	~$110,000 USD	~$50,000 USD	~$60,000 USD
Average Lead Time	10–12 weeks	3–4 weeks	~8 weeks saved

4.6 Summary of Validation Outcomes: Table 2

Table 2: OEM vs Refurbished Comparison Table

Test / Parameter	OEM Standard	Refurbished Result	Status
Surface Tension (N/cm)	5–7	5–7	Within Spec
Pressure Hold (60 sec)	No drop below 1 bar	Passed (all 10 membranes)	Compliant
Airflow Uniformity	Stable laminar flow	Verified via probes and smoke test	Compliant
Visual Cleanroom Acceptance	No cracks, flat seal	Passed visual inspection	Acceptable
Overall Cost Efficiency	11000 USD	55% cost savings (~$60,000 USD)	Achieved

Conclusion from Results

The refurbishment of CG membranes provided equivalent functional performance to new OEM components across all key validation parameters, including surface tension, airflow uniformity, pressure retention, and cleanroom suitability as shown in the table 2. At the same time, the project delivered a 55% cost reduction and eliminated extended OEM lead times, making this a highly attractive option for facilities seeking to improve operational efficiency, reduce waste, and maintain GMP compliance. These findings strongly support the case for expanding component refurbishment practices within pharmaceutical manufacturing as a sustainable and reliable alternative to replacement.

5. Discussion

The pharmaceutical industry is governed by strict quality and compliance expectations, particularly in aseptic manufacturing environments where product sterility is paramount. To meet these standards, manufacturers often rely on original equipment manufacturer (OEM) components and full replacements as the default strategy when equipment shows signs of wear. While this practice ensures reliability, it also leads to high operational costs, longer lead times, and unnecessary environmental waste—especially in cases where components may be structurally and functionally repairable.

This paper set out with a clear objective: to demonstrate that refurbishment of critical GMP components can be a cost-saving, reliable, and regulatory-compliant alternative to full replacement. The case study involving the refurbishment of 11 CG (Ciba Geigy) membranes used in a commercial-grade vial filling isolator provides tangible evidence in support of this position.

Following a structured and validated refurbishment process including cleaning, seal reconditioning, surface tension testing, pressure hold evaluation, and airflow performance checks the membranes were returned to service and requalified within GMP standards. Importantly, the results showed no performance loss when compared to OEM components, across all key parameters including pressure retention, laminar airflow integrity, and cleanroom suitability. The membranes-maintained surface tension values within the required 5–7 N/cm range and passed visual inspections and airflow testing consistent with Grade A environment requirements.

Beyond the technical success, the refurbishment initiative yielded a 55% cost reduction, saving approximately $60,000 USD compared to full OEM replacement. Additionally, the turnaround time was reduced by more than 8 weeks, significantly decreasing the risk of extended production downtime. This alone presents a convincing case for rethinking standard maintenance approaches in high-throughput pharmaceutical operations.

More broadly, this study highlights the untapped potential of refurbishing high-value components across the pharmaceutical sector. While certain parts—such as pumps, gaskets, or seals—are often replaced without question, many can be requalified using documented, risk-based protocols aligned with FDA and EU GMP expectations. When refurbishment is carried out using validated methods and supported by quality testing, it becomes a compliant, sustainable practice that offers measurable return on investment.

Refurbishment also supports wider industry goals related to supply chain resilience and sustainability. By reducing

dependence on single-source OEM suppliers and extending component life cycles, manufacturers gain more control over inventory management and maintenance scheduling. Furthermore, less frequent disposal of mechanical parts reduces environmental impact — a growing concern in GMP facility operations and regulatory frameworks alike.

While this paper focused on one specific case—CG membranes in a Grade A isolator—the approach and outcomes are universally applicable. With the right risk assessment, material knowledge, and validation strategy, comparable results can be achieved with other isolator components, filtration systems, mechanical subassemblies, and even instrumentation housings.

In conclusion, this study provides a strong proof of concept that supports the central thesis: Refurbishment is not only possible in GMP manufacturing—it is practical, economical, and sustainable. Pharmaceutical facilities that adopt such strategies can reduce operational costs, avoid production delays, and maintain compliance without sacrificing quality. Future work may include expanding this approach to additional component types and publishing broader case studies to encourage adoption across the industry.

Future Work:

The successful refurbishment of CG membranes within a Grade A isolator sets a promising foundation for broader application of this methodology across other sterile manufacturing systems. As a next step, this validated approach will be applied to CG membranes located within Restricted Access Barrier Systems (RABS) and the capping station (capper) isolator—both of which play critical roles in maintaining sterility during vial filling operations. These components, like the original case study membranes, are often subject to wear, contamination, and high replacement costs, making them strong candidates for similar refurbishment.

In addition, the expansion of this refurbishment methodology to other isolator components, such as glass panels, glove ports, valve housings, and filter frames that may unlock further operational savings and contribute to sustainability goals**.** Each component class will require its own set of risk assessments, cleaning procedures, and validation protocols to meet regulatory expectations and ensure continued GMP compliance.

This initiative aims to establish a scalable, facility-wide refurbishment framework that balances cost-efficiency, compliance, and environmental responsibility—providing a new model for proactive asset management in modern pharmaceutical manufacturing.

CONCLUSION

This paper demonstrates that refurbishing critical GMP components—specifically, CG (Ciba Geigy) membranes in a commercial isolator—is a cost-effective, reliable, and GMP-compliant alternative to full OEM replacement. Through a validated process that included cleaning, reconditioning, and comprehensive performance testing, refurbished membranes delivered equivalent functionality to new components while reducing costs by over 55% and avoiding prolonged lead times.

The success of this case study supports the broader proposition that strategic refurbishment can be adopted across pharmaceutical facilities to optimize maintenance budgets, reduce environmental waste, and improve operational resilience. In a highly regulated industry where equipment performance is tied directly to product safety, this approach offers a sustainable pathway for balancing compliance with cost control.

As pharmaceutical manufacturing continues to evolve in response to global supply chain pressures and sustainability goals, initiatives like this one provide replicable, real-world examples of innovation within existing regulatory frameworks. By extending the lifecycle of high-value components without compromising sterility or safety, refurbishment presents a practical model for continuous improvement in modern GMP operations.

This study is not just a technical report — it is a call to reconsider traditional maintenance strategies in the pharmaceutical sector. With the right controls, data, and expertise, refurbishment can and should be part of the industry's toolkit for delivering safe, cost-effective, and sustainable healthcare solutions.

Declarations

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