

# REDUCING LANDFILL FLOWS THROUGH REMANUFACTURING: AN LCA OF DAVIES OFFICE FURNITURE WORKSPACES

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## Abstract

Office furniture represents a significant portion of the U.S. EPA-estimated 9.7 million tons of discarded furniture generated annually, contributing to durable-goods landfill flows<sup>1 2</sup> highlighting the need for scalable circular-economy strategies. Remanufacturing offers a high-value pathway to reduce these impacts by retaining durable components, extending product life, and conserving embodied material and energy.

To quantify the environmental benefits of remanufacturing relative to disposal and new production, this study applies an ISO-aligned life cycle assessment (LCA) and draws on third-party-verified Environmental Product Declarations (EPDs) to establish transparent, comparable performance benchmarks. This approach addresses a gap in the literature, where few LCAs document the environmental outcomes of remanufactured office furniture systems.

The LCA along with EPA disposal estimates, detailed material composition data, remanufacturing process inventories, and EPD-verified impact factors is used to evaluate global warming potential, ozone depletion, material conservation, and avoided upstream production burdens. The assessment evaluates the environmental consequences of retaining and restoring structural steel frames, connectors, and other durable components, while accounting for the selective use of new materials where required. Operational throughput and diversion performance are incorporated to contextualize potential system-level benefits.

Results show that office systems contain a high proportion of steel, often close to 60% of structural mass, making them particularly well-suited for remanufacture and reuse. When applied at current throughput, the remanufacturing model demonstrates substantial reductions in embodied emissions and landfill flows, with the potential to avoid approximately 28,941 metric tons of CO<sub>2</sub>-eq and divert 3,465 metric tons of material from landfill over a decade.

These findings demonstrate that remanufacturing delivers meaningful environmental benefits at scale and highlight the value of EPD-supported LCA as a rigorous, transparent framework for substantiating circular-economy outcomes in the office furniture sector.

## Introduction and Motivation

Office furniture represents a substantial and growing contributor to landfill flows in the United States. According to the U.S. Environmental Protection Agency, an estimated 9.7 million tons of furniture are discarded annually, with office furniture comprising a significant share of this durable goods waste stream.<sup>3</sup> Although the U.S. office furniture industry continues to grow, most systems are still discarded at end-of-use, resulting in lost material and embodied-energy value.<sup>4 5</sup>

Most office furniture systems are constructed as bulky, mixed-material assemblies that combine steel with particleboard, plastics, textiles, and adhesives. This makes disassembly labor-intensive and economically unfavorable for recyclers who require clean, single-material streams.<sup>6 7</sup> As a result, recyclers and scrap yards often reject these products, and most decommissioned systems are ultimately routed to landfill.<sup>8 9</sup> This presents both a challenge and an opportunity: scalable strategies for diversion and circular recovery could significantly reduce environmental burdens while extending the functional life of high-value products through remanufacturing.

Remanufacturing restores a worn product to a like-new condition through selective disassembly, inspection, and replacement of degraded components. By recovering and reusing viable parts, remanufacturing preserves the

materials and energy embodied in the original product and reduces the need for energy-intensive primary production.<sup>10</sup>.

This paper presents a life cycle assessment (LCA) of the Davies Office’s remanufactured SC® Answer office system (Reman Answer), a remanufactured office furniture solution designed to extend product life and recover embedded material and energy value. Remanufacturing offers a high-leverage strategy for circularity by retaining core components, especially steel frames and connectors that would otherwise require energy-intensive primary production.

The study applies ISO 14040/44-compliant LCA methods and incorporates a third-party-verified Environmental Product Declaration (EPD) to establish transparent, reproducible performance benchmarks. The analysis quantifies cradle-to-gate environmental impacts across collection, triage, refurbishment, and reassembly and addresses three questions: (1) What environmental impacts, global warming potential, primary energy demand, and landfill mass, are avoided per unit through remanufacturing? (2) How do cradle-to-gate impacts of the Reman Answer compare to new office furniture? and (3) What benefits can be achieved when remanufacturing is scaled to typical throughput volumes over a 10-year horizon?

The LCA also identifies material and process hotspots that influence environmental performance and informs the development of the Reman Answer EPD. This study contributes by delivering a third-party-verified EPD for a remanufactured office workspace, quantifying environmental outcomes over a 10-year reference service life, and identifying targeted opportunities to increase circularity and reduce lifecycle impacts.

## Review of Related Work

A targeted review of recent product declarations found seven ISO-style EPDs covering a cross-section of contemporary office furniture systems: Steelcase Answer<sup>11</sup>; Herman Miller Action Office and Layout Studio<sup>12 13</sup>; Knoll Dividends Horizon<sup>14</sup>; and Teknion Leverage, District, and Expansion Cityline<sup>15 16 17</sup>. Together these EPDs represent diverse construction approaches (steel-heavy frames through board-based assemblies), a range of product masses, and multiple manufacturer reporting practices, providing a pragmatic sample set for comparing lifecycle hotspots, normalization strategies, and the methodological variability that complicates direct comparisons. The product comparison from each EPD is shown in Table 1.

Table 1: Office Furniture EPD Comparison

Manufacturer	Product	FU (m <sup>2</sup> / 10 yr)	Total GWP (kg CO <sub>2</sub> -eq/m <sup>2</sup> )	Recycled Content (%)	RSL (yrs)
Herman Miller	Layout Studio (EPD11118)	1	~106	29	10
Knoll	Dividends Horizon (EPD11110)	1	~269	62	10
Herman Miller	Action Office (EPD10643)	1	~152	29	10
Teknion	Leverage (EPD10186)	1	~167	56	10
Teknion	District (EPD10187)	1	~125	82	10
Teknion	Expansion Cityline (EPD10245)	1	~153	82	10
Steelcase	Answer (EPD10739)	1	~349	30–40	10
Davies Office	Reman Answer (this study)	1	~75	~65 Retained	10

The reviewed EPDs consistently identify material acquisition and production stages (A1–A3) as the dominant contributors to cradle-to-gate global warming potential (GWP) and primary energy demand for representative

systems. Products with high steel content show the largest absolute GWP values, while products dominated by particleboard/MDF concentrate impacts in the material-acquisition sub-stage; consequently, absolute product mass and the steel/board material split strongly govern emissions. However, direct comparison of EPDs is complicated by differing functional units and reference service lives (RSLs), inconsistent inclusion or presentation of biogenic carbon, variation in end-of-life credits (module D), and use of different LCI databases and software tools. This diversity requires normalization (e.g., per kg, per m<sup>2</sup> per year, per seat-year) and careful reconciliation of stage boundaries before direct comparisons can be justified.

Complementing this EPD review, a detailed LCA case study of Davies Office's adaptive remanufacturing practice demonstrates how iterative, market-adaptive remanufacturing workflows can materially extend useful life and increase cumulative environmental benefits compared to single-cycle remanufacturing or virgin production.<sup>18</sup> The Davies study shows that adaptive strategies (indexing, selective reconfiguration, and targeted component replacement) can sustain high reuse yields across multiple cycles, keep per-cycle manufacturing energy substantially below OEM levels, and produce meaningful cumulative reductions in cumulative energy demand (CED) and material-use impacts when results are reported on combined lifecycle bases.<sup>18</sup> Together, the manufacturer EPDs and the Davies adaptive-remanufacturing LCA illustrate both the promise of remanufacturing to reduce cradle-to-gate burdens and the current gap in ISO-aligned, EPDs that explicitly represent remanufactured or adaptively remanufactured office furniture.<sup>18</sup>

Despite the demonstrated potential of remanufacturing, there is a distinct absence of third-party verified, ISO-aligned EPDs for remanufactured office furniture. Manufacturer EPDs almost exclusively represent new-product supply chains and omit remanufacturing process steps (collection logistics, disassembly, selective replacement, reassembly, and redistribution).

## Technology Approach

The objective of this study is to conduct an ISO 14040/44 and ISO 21930 compliant life cycle assessment (LCA) that: (1) quantifies the relative contribution of processes, materials, and life cycle stages of the Reman Answer to environmental impact, (2) evaluates how impacts accumulate across the modeled life-cycle modules, and (3) support the publication of an Environmental Product Declaration (EPD) quantifying the impacts of the Reman Answer.

### Impact Assessment Method

TRACI 2.2 and IPCC 2021 GWP100 version 1.03 are used to assess the environmental impacts of the Reman Answer. The impact categories analyzed include global warming potential, ozone depletion potential, eutrophication potential, acidification potential, smog (photochemical oxidant creation potential), and biogenic GWP. ReCiPe 2016 Midpoint (H) V1.09 and Cumulative Energy Demand (LHV) V1.01 are applied to calculate the water consumption and Renewable/non-renewable primary energy consumption respectively in accordance with ISO 21930 and the ACLCA guidance for non-LCIA inventory metrics.

### System Boundary

This study uses a cradle-to-gate LCA that follows an attributional, cut-off approach consistent with ISO 14040/44, ISO 21930, and the NSF 1101-25 Product Category Rule (PCR)**Error! Bookmark not defined.** for office furniture workspaces. The system boundary includes all processes associated with remanufacturing one Reman Answer workstation and covers life-cycle modules A1 through A3, B4, and C1 through C4.

Module A1 includes the extraction and upstream production of materials used in replacement components, laminate, and coating powder. Module A2 models the transport of returned workstations and new replacement parts to the Davies facility. Module A3 represents all remanufacturing activities, including disassembly, cleaning, refinishing, coating, and reassembly.

Use-stage modules are largely excluded: B1 (use-phase energy) is excluded because office furniture has no operational energy use; B2 (maintenance), B3 (repair), and B5 (refurbishment) are excluded because no such activities are required within the functional unit; and B4 is included only for the transport of any replacement components, with no additional manufacturing burdens assigned. End-of-life processes are fully included, with C1 representing deconstruction, C2 representing transport to waste processing or disposal, C3 representing recycling preparation, and C4 representing final disposal of non-recyclable materials.

Modules A4 (transport to customer) and A5 (installation) are excluded in accordance with the PCR due to high variability in customer locations and the fact that the workstation arrives fully assembled. Consistent with the cut-off approach, the assessment quantifies only the environmental burdens directly attributable to the remanufactured unit; original OEM production burdens are excluded. Upstream impacts for new replacement components are fully included to ensure that all incremental burdens associated with restoring a used workstation to service are fully captured.

## Transportation

Transportation is modeled in accordance with the NSF 1101-25 PCR and reflects the logistics associated with the remanufacturing of the Reman Answer workstation. Inbound transport of returned workstations to the Davies facility is included in Module A2 and modeled using long-haul heavy-duty trucking over an average distance of 800 miles, with a sensitivity range of 200–1,600 miles to capture geographic variability in customer return locations. Transport of new replacement components to the facility is also included in A2 and modeled using representative regional freight distances consistent with North American supply chains.

Outbound shipment of the remanufactured workstation to customers (A4) is excluded from the system boundary, as allowed by the PCR, due to the high variability of customer locations and the lack of standardized delivery distances for office furniture. End-of-life transport (C2) is included and modeled using standard waste transport assumptions. This approach provides consistent representation of transportation impacts across the life cycle while maintaining comparability with PCR-aligned office furniture LCAs.

## Assumptions

The LCA uses primary 2023–2024 process data from the Davies facility to characterize material flows, remanufacturing operations, and energy use, with electricity and natural gas allocated based on measured equipment loads and throughput. Upstream impacts for new replacement components are modeled using representative North American datasets and conventional manufacturing energy mixes. Transportation distances for inbound returns, supplier deliveries, and outbound shipments are standardized to average values aligned with PCR defaults.

No routine maintenance or repair is assumed during the 10-year reference service life, and no renewable energy certificates or offsets are applied. The study follows an attributional cut-off approach in which only the incremental burdens of remanufacturing are included; original OEM production is excluded, while upstream impacts for new parts and disposal of replaced components are fully counted. These assumptions provide a consistent basis for evaluating the environmental performance of the remanufactured system.

## Sensitivity

The sensitivity analysis evaluates how uncertainties in key material and energy processes influence the modeled impacts of the Reman Answer system. Two energy-related processes exceeded the PCR's 1% contribution threshold: the modified NYUP medium-voltage electricity mix, representing 96.8% of total electricity use, and the Davies welding process, contributing 3.2%. Both processes are adapted fromecoinvent datasets and refined using EPA regional electricity data and primary measurements of weld gas composition and electricity consumption.

Following PCR guidance, each process is modeled at its baseline value, at half that value, and at double that value. Impacts were recalculated in SimaPro using TRACI 2.2 and IPCC GWP100 methods and compared to the total cradle-to-gate impacts of the Reman Answer. This approach offers a transparent assessment of how variations in electricity modeling, welding operations, and material processes influence the robustness of the LCA results.

## Functional Unit

The function of the modeled system is to provide one person with a working area that is separate from another person's working area. The functional unit in this study is one square meter (1.0 m<sup>2</sup>) of workspace for a 10-year period. The product is intended to last longer than 10 years and has a lifetime warranty, giving it a RSL of 10 years.

## Product Description

The Davies' Reman Answer modeled in this study is a conventional office cubicle workspace, intended for one occupant, representative of a typical remanufactured office workspace from Davies and is illustrated in Figure 1. The system includes a two-piece L-shaped worksurface and a wall panel system with two panels for workspace separation.

It also has an overhead shelf, an overhead bin, a pedestal for under-desk storage, and two supports for the worksurface. All components are stationary. The system covers 2.54 m<sup>2</sup> of floor space, providing 1.49 m<sup>2</sup> of worksurface and 0.26 m<sup>3</sup> of storage capacity.

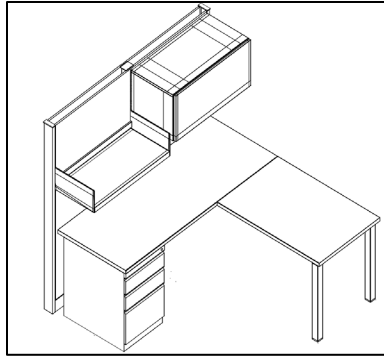


Figure 1 - Diagram of Reman Answer configuration.

The Reman Answer material composition is dominated by steel at almost 65% followed by wood at just under 23%. A full breakdown of the Reman Answer material composition is shown in Table 2.

Table 2: Reman Answer Material Composition

Material	Material weight (kg)	Percent of product (%)
Steel	82.6	64.9%
Plastic	7.8	6.1%
Fabric	1.1	0.9%
Wood	29.0	22.8%
Fiberglass	4.9	3.9%
Powder coat	1.3	1.0%
Adhesive	0.5	0.4%
TOTAL	127.2	100.0%

Returned cores are transported from various locations across the continental United States to the Davies remanufacturing facility. The workflow follows a series of defined steps:

1. Inspection and triage
2. Disassembly and selective component recovery
3. Surface preparation (degreasing, sanding) and recoating/curing
4. Panel upholstery replacement (removing old fabric, applying new fabric)
5. Fabrication of new worksurfaces and supports (particleboard lamination, welded steel supports)
6. Final assembly, packaging, and shipping to the customer
7. In-service use and eventual decommissioning, followed by transport to local disposal at end of life

Primary data for the life cycle inventory (LCI), including process energy, material masses, and packaging specifications, was collected at the Davies facility and reflects operations in 2023–2024.

## Discussion

The overall results of the life cycle impact assessment for the six impact categories of interest are shown in Table 3. The Reman Answer system has a cradle-to-gate GWP of 75.2 kg CO<sub>2</sub>-eq per square meter. This value reflects only the incremental burdens associated with remanufacturing, consistent with the cut-off approach.

Table 3 - Summary of Reman Answer Impacts

Impact category	Unit	Total
Ozone depletion	(kg CFC-11 eq)	1.53E-05
Global warming	(kg CO <sub>2</sub> eq)	75.2
GWP100 biogenic	(kg CO <sub>2</sub> eq)	2.84
Smog	(kg O <sub>3</sub> eq)	4.30
Acidification	(kg SO <sub>2</sub> eq)	0.246
Eutrophication	(kg N eq)	0.511

Table 4 summarizes the allocation of impacts across life-cycle modules. Module A1 (raw material extraction) remains the dominant contributor to ozone depletion potential, contributing 94% to the impact. Global warming potential (GWP) is primarily driven by Module A1 and Module A3 (manufacturing), each contributing 35%, with transportation (A2) contributing 17%. Smog formation follows a similar pattern, contributing 40% from Modules A1 and A3, and a 35% contribution from A2 (transportation). Acidification potential is also largely influenced by A1. In contrast, eutrophication potential is most significantly affected by Module C4 (disposal), which contributes 67% of the total impact.

Table 4: Impact Allocation by Module

Impact category	Unit	A1 - Raw Material Extraction	A2 - Transport	A3 - Manufacturing	A3 - Packaging	B1 - Use	C1 - De-Construction	C2 - Transport	C4 - Disposal
Ozone depletion	kg CFC-11 eq	94%	1.5%	3%	1%	0.0%	0.0%	0.1%	0.1%
Global warming	kg CO <sub>2</sub> eq	35%	17%	35%	5%	0.0%	0.0%	1%	8%
biogenic	kg CO <sub>2</sub> eq	5%	0.1%	41%	7%	0.0%	0.0%	0%	46%
Smog	kg O <sub>3</sub> eq	40%	35%	16%	6%	0.0%	0.0%	1%	2%
Acidification	kg SO <sub>2</sub> eq	51%	24%	16%	6%	0.0%	0.0%	1%	1%
Eutrophication	kg N eq	18%	3%	9%	3%	0.0%	0.0%	0.1%	67%

Indicators of primary resource use were calculated following ISO 21930 and include: non-renewable primary energy demand, renewable primary energy demand, and net freshwater consumption. Energy demand values were derived from the CED (LHV) method (V1.01). Renewable primary energy demand is the sum of the renewable categories (biomass; wind, solar, geothermal; and water), while non-renewable primary energy demand is the sum of the non-renewable categories (fossil; nuclear; and non-renewable biomass). Net freshwater consumption is reported using the water-consumption midpoint from ReCiPe 2016 Midpoint (H) V1.09. The results on the impact assessment are shown on Table 5.

Table 5 -Reman Answer Impact Assessment of Energy and Water

Inventory assessment categories	Unit	Total	A1	A2	A3	A3	B1	C1	C2	C4
CED, Non-renewable	MJ	1175	427	191	487	54.7	2.01E-03	2.73E-03	8.87	6.86
CED, Renewable	MJ	307	239	2.61	24.8	40.5	5.13E-04	2.87E-04	0.119	0.233
Water Consumption	m <sup>3</sup>	0.410	0.30	0.0271	0.0878	0.0250	1.02E-06	9.39E-07	1.28E-03	-0.0409

Interpretation of hotspots

Material acquisition and manufacturing (A1–A3) dominate most impact categories, consistent with published EPDs for new furniture. For Reman Answer, retaining steel frames reduces incremental A1 burdens significantly compared

to new production because the original OEM steel burdens are not reassigned to the remanufactured product. However, replacement of certain finishing materials, polyester fabrics, and addition of new supports/work surfaces introduces upstream burdens that partially offset remanufacturing benefits.

Beyond these hotspots, two additional considerations strengthen the relevance and robustness of the findings. Although the LCA is modeled on a single Reman Answer workstation, the per-unit functional unit is required by ISO 14040/44 and the NSF 1101-25 PCR and provides a consistent basis for comparison with new-product EPDs. The implications of the results, however, extend well beyond an individual system. Because the environmental benefits of remanufacturing scale linearly with throughput, the avoided impacts associated with material production, coating, and laminate manufacturing increase proportionally as more workstations are diverted from landfill and returned to service. When applied to typical annual remanufacturing volumes, the per-unit avoided impacts translate into several hundred metric tons of CO<sub>2</sub>-eq avoided each year, along with substantial reductions in virgin material demand and waste generation. This demonstrates that the findings are directly applicable to large-scale remanufacturing programs and corporate procurement strategies seeking to reduce embodied carbon and extend product life.

### Sensitivity

A sensitivity analysis was conducted to evaluate the robustness of the results and provide additional transparency. The sensitivity results show that most modeled processes have a limited influence on overall environmental performance, confirming the stability of the Reman Answer results. The steel and plastic part processes and the Davies welding process remained below the 1% significance threshold across all impact categories, even when their contributions were halved or doubled. In contrast, the laminate and powder coating processes demonstrated meaningful sensitivity across multiple impact categories. Laminate contributed 2.1–7.7% of global warming impacts, 1.8–7.0% of smog formation, 2.2–4.3% of eutrophication, and 2.8–10.2% of acidification. The powder coating process contributed 2.9–10.6% of global warming, 3.1–11.2% of smog formation, 3.5–6.7% of eutrophication, and 4.1–14.7% of acidification. The created electricity process showed smaller but measurable influence, contributing 2.1–4.0% of global warming, 0.6–1.2% of smog formation, and 0.7–1.5% of acidification. These findings highlight that uncertainties in laminate production and surface finishing have the greatest potential to shift impact results, while uncertainties in electricity modeling, welding, and minor component flows do not materially affect the study's conclusions. Overall, the sensitivity analysis confirms that the environmental advantages of remanufacturing are stable across a wide range of assumptions and that the primary drivers of variability are well understood and limited in scope.

### Implications for procurement and design

- Procurement: Include remanufactured product declarations in sustainable frameworks and request EPDs that clearly disclose remanufacturing steps and assumptions.
- Design: Prioritize reducing high-impact new replacements (worksurfaces, supports) and substitute lower-impact fabrics for panels (recycled fibers, lower-ozone-depletion alternatives).
- Operations: Improve remanufacture yield through more selective triage and refurbished parts inventory to reduce need for new parts.

### Limitations

- Original OEM production burdens for returned cores were not modeled and thus avoided burdens in this attributional approach; results should be interpreted as the incremental burdens of remanufacturing (including replacement parts), not as full multi-cycle life cycles.
- Scaling results depend on throughput, yield, and market penetration assumptions; reported decade totals are illustrative and sensitive to these parameters.

### Comparison with new-product EPDs

Direct comparisons require normalization to functional unit and RSL. Where normalized comparisons are possible, Reman Answer shows lower cradle-to-gate GWP per m<sup>2</sup> per 10-year RSL than representative new-product EPDs with similar service lives, particularly for steel-heavy configurations. It is recommended that comparisons use normalized metrics (e.g., kg CO<sub>2</sub>-eq per m<sup>2</sup> per year) and explicit notes on boundaries.

In comparing the Reman Answer system with the Steelcase new Answer system<sup>19</sup>, the analysis shows the substantial environmental benefits of remanufacturing at scale. Each remanufactured system retains approximately 83 kg of material that would otherwise be landfilled, resulting in an annual diversion of over 346 metric tons and more than 3,465 metric tons over a decade at current throughput. When normalized to the functional unit, the cradle-to-gate

global warming potential of the Reman Answer is 75.2 kg CO<sub>2</sub>-eq per m<sup>2</sup>, translating to 191 kg CO<sub>2</sub>-eq for the 2.54 m<sup>2</sup> system. In contrast, the Steelcase new Answer system reports 349 kg CO<sub>2</sub>-eq per m<sup>2</sup> (A1–A3), or nearly 887 kg CO<sub>2</sub>-eq per system. This yields a per-system reduction of roughly 696 kg CO<sub>2</sub>-eq, which scales to nearly 2,900 metric tons avoided annually and close to 29,000 metric tons avoided over ten years, Table 6.

Table 6: Results summary for Reman Answer compared to Steelcase new Answer system (normalized to 2.54 m<sup>2</sup> system). Values shown per system, annual throughput of 4,160 systems, and cumulative 10-year totals.

Metric	Per system	1 year (4,160 systems)	10 years
Avoided landfill mass	83.3 kg	346,528 kg (346.53 MT)	3,465,280 kg (3,465.28 MT)
GWP, Reman Answer (A1–A3)	191.01 kg CO <sub>2</sub> -eq	—	—
GWP, New Answer (A1–A3)	886.71 kg CO <sub>2</sub> -eq	—	—
GWP reduction	695.70 kg CO <sub>2</sub> -eq	2,894,112 kg CO <sub>2</sub> -eq (2,894.11 MT)	28,941,120 kg CO <sub>2</sub> -eq (28,941.12 MT)

Figure 2 illustrates the change in cradle-to-gate global warming potential (GWP) between a new Steelcase Answer system and the remanufactured Reman Answer system. The chart highlights the avoided upstream burdens attributable to remanufacturing and the resulting net GWP of the remanufactured unit.

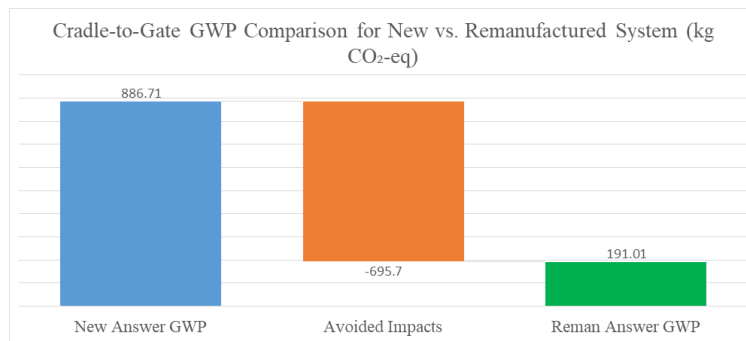


Figure 2: Cradle-to-Gate GWP Comparison for New vs. Remanufactured System (Per System)

Figure 3 illustrates the cumulative 10-year GWP reduction associated with remanufacturing at current throughput levels.

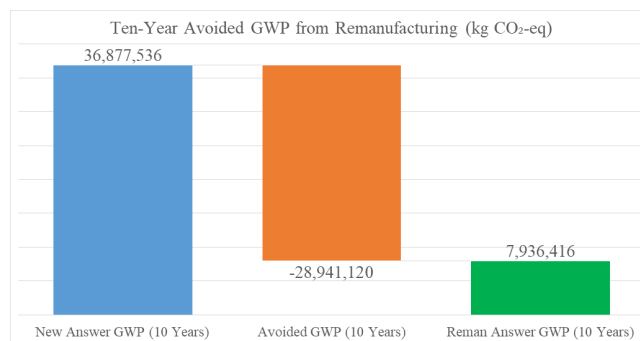


Figure 3: Ten-Year Avoided GWP from Remanufacturing

These results underscore that remanufacturing not only diverts significant tonnage from landfill but also delivers large reductions in embodied greenhouse gas emissions compared to new production. The findings highlight the dual value proposition of remanufacturing, material conservation, and climate impact mitigation, and reinforce the importance of integrating remanufactured product EPDs to credibly capture these benefits.

## Conclusions & Recommendations

The results show that remanufacturing office furniture provides clear environmental advantages by retaining steel components and limiting new material production. The Reman Answer system reduces cradle-to-gate global warming potential, energy demand, and landfill mass relative to new manufacturing. Performance is driven primarily by the extent of component reuse and the quantity of new materials required, with worksurfaces, supports, laminate, and coating powder contributing most to remaining impacts. Modules A1, A3, and C4 dominate global warming, smog, acidification, and biogenic carbon emissions, while new polyester fabric in the Panels subassembly is the main driver of ozone depletion.

Remanufacturing also yields substantial material-diversion benefits. Each workstation retains about 83 kg of components, resulting in 346 metric tons of annual diversion and nearly 3,465 metric tons over ten years. Cradle-to-gate impacts total 75.2 kg CO<sub>2</sub>-eq per m<sup>2</sup>, or 191 kg CO<sub>2</sub>-eq per system, compared to 887 kg CO<sub>2</sub>-eq for a new Steelcase Answer—an avoided burden of roughly 696 kg CO<sub>2</sub>-eq per workstation. At current throughput, this equates to nearly 2,900 metric tons of avoided emissions annually and close to 29,000 metric tons over a decade. These results demonstrate that remanufacturing can meaningfully support organizational carbon-reduction goals and circular procurement strategies.

The sensitivity analysis reinforces the robustness of the study's conclusions. Most modeled processes including steel, plastics, welding, and electricity had only minor influence on overall impacts, indicating that uncertainties in these areas do not materially affect comparative results. In contrast, laminate and coating powder were the most responsive to parameter changes, suggesting that surface finishing and laminate production have the greatest potential to shift impact outcomes. These findings highlight that maintaining high reuse rates and minimizing the need for new worksurfaces and supports remain the most effective strategies for improving environmental performance.

Several opportunities for improvement emerge from this analysis. Increasing the proportion of remanufactured components particularly worksurfaces and structural supports would further reduce upstream burdens. Substituting polyester fabric with recycled or lower-impact alternatives could significantly reduce ozone depletion potential. Exploring alternative laminate chemistries, lower-impact coating systems, or design modifications that reduce surface finishing requirements may also yield meaningful reductions. At the system level, expanding take-back programs and improving yield in the disassembly and refurbishment stages would amplify both material diversion and avoided emissions. Future work should evaluate the durability, performance, and supply-chain feasibility of proposed material substitutions, as well as the potential benefits of integrating renewable energy or low-carbon transportation into remanufacturing operations.

Overall, this study demonstrates that remanufacturing is a high-leverage strategy for advancing circularity in the office furniture sector. By combining substantial landfill diversion with significant reductions in embodied greenhouse gas emissions, remanufactured systems offer a credible, scalable pathway for organizations seeking to meet sustainability and procurement goals. Environmental Product Declarations (EPDs) further strengthen this value proposition by providing transparent, standardized reporting that enables customers, designers, and policymakers to compare products on a consistent basis and make informed, climate-aligned decisions.

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