Life Cycle Assessment Results:

Comparison of a Remanufactured Steelcase Avenir® Office System at Davies Office, Inc. to an OEM Office System

FINAL REPORT

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Acknowledgements and Disclaimers

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Executive Summary

The Center of Excellence in Advanced & Sustainable Manufacturing (COE-ASM) at the Rochester Institute of Technology (RIT) was commissioned by Davies Office, Inc. to perform life cycle assessments on their remanufactured Steelcase Avenir® office workspace products and compare environmental impacts to new Steelcase products.

The goal of this study is to compare the environmental impacts of remanufactured office furniture products to those of the originally manufactured products (OEM). This study uses Life Cycle Assessment (LCA) methodologies to quantify the environmental impacts of each product holistically throughout the entire life cycle; from material extraction to manufacturing, transportation, use, and end-of-life. The impacts associated with each product are assessed by compiling an inventory of relevant energy and material inputs and environmental releases, evaluating the potential environmental impacts associated with these inputs and releases, and interpreting the results to help make more informed decisions.

Life cycle models in this assessment are constructed using the SimaPro 8.0.4 modelling software in conjunction with both the ecoinvent 3 database and actual collected product and process data. These models evaluate the environmental impacts of the remanufacturing life cycle as both independent of the OEM and dependent on, or combined with, the OEM. The independent life cycle method is used to indicate the side by side comparison of the OEM, Reman 1 and Reman 2 Office Systems based solely on the materials and processes used to make each office system component. The combined model is used to indicate how the average impact of the office system population is affected by multiple remanufacturing cycles compared to the OEM. The combined model aggregates the impacts for each product life cycle and distributes them evenly across all life cycles. The combined method thus shares the OEM burden across all life cycles.

The office system life cycles compared throughout this report are defined as:

- OEM—The office system manufactured at Steelcase (SC), the original equipment manufacturer (OEM). This consisted of a divider panel, work surface, storage pedestal and a 2 drawer lateral file. The complete office system will be comprised of several work surfaces and panels along with one pedestal and one file. The complete office system is further defined in section 2.3.2.
- Reman 1—An office system that has been remanufactured by Davies from a Steelcase OEM office system
- Reman 2 (also referred to as Reman Avg.)—An office system remanufactured by Davies from a Steelcase office system that had already been previously remanufactured at least one time.

The study system boundary is set up to specifically compare the life cycle of a remanufactured office system to the OEM. The life cycle for reman and OEM is cradle to grave from raw material extraction and component production to end of life disposition. Use phase of both Davies and the OEM fall within the boundary, however it is assumed that both office systems will experience similar use and impacts therefore this phase of the life cycle is ignored. The primary focus was on the manufacturing stage of the office system products and the related inputs and outputs.

This life cycle assessment has been performed in accordance with ISO 14040:2006(E) *Environmental management—Life cycle assessment—Principles and framework* with a critical review performed by an LCA expert external to this project.

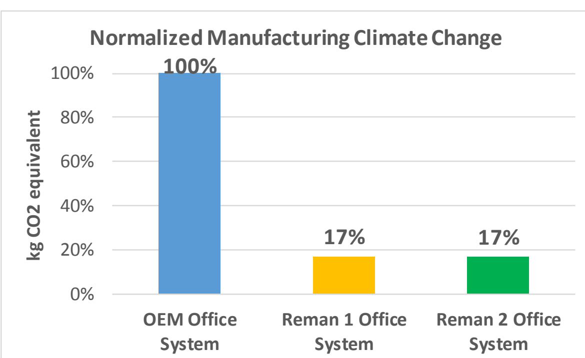
If the results of this LCA are to be disclosed to the public, ISO 14044 section 6.1 requires that "a panel of interested parties conduct critical reviews" on results and comparative claims.

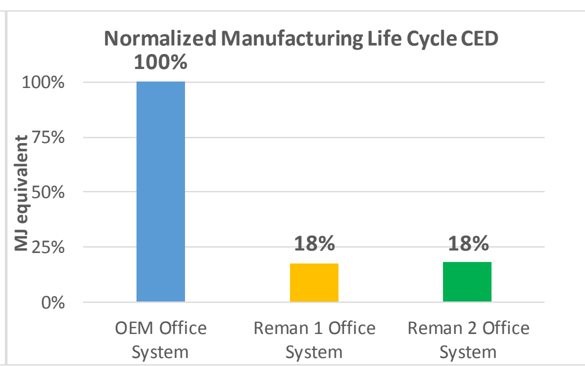
Significant Results

The LCA models the life cycle impacts in 18 categories represented by the ReCiPe version 1.11, 2014 midpoint+ method, and Cumulative Energy Demand (CED) 1.09. Data from both the OEM LCA and Davies were modeled using ReCiPe version 1.11, 2014. This section highlights the significant results identified in the LCA.

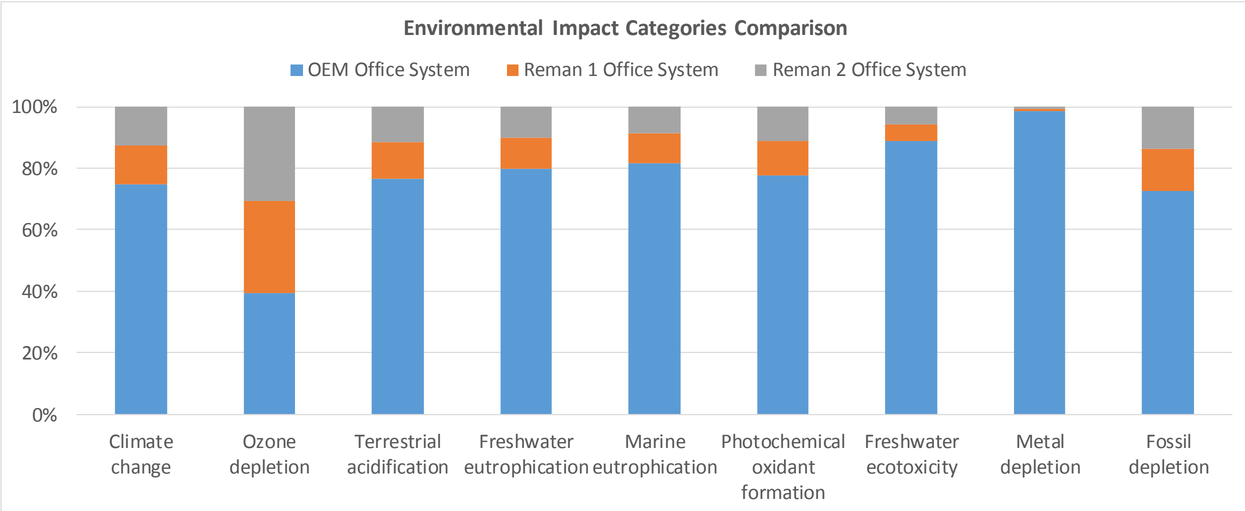
OEM, Davies first and second remanufacturing life cycle compared (independent life cycle method)

- The Davies first and second remanufacturing life cycle are the same and 17 percent of the OEM life cycle from cradle to gate for climate change impacts. During the first remanufacturing life cycle it is common for Davies to take OEM panels and storage components and resize them by decreasing the overall height, to promote a more open collaborative office space. Additional processing and scrap may be generated during Reman 1 though these contributions to the impacts are very small.



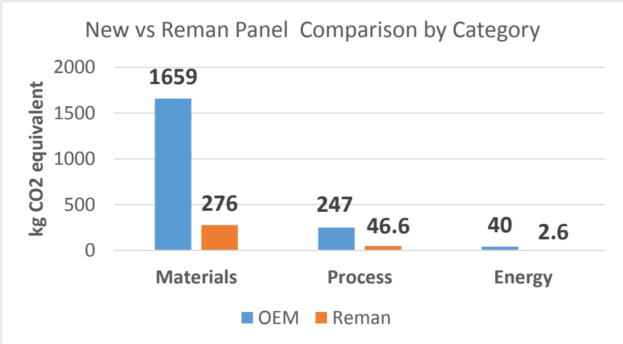


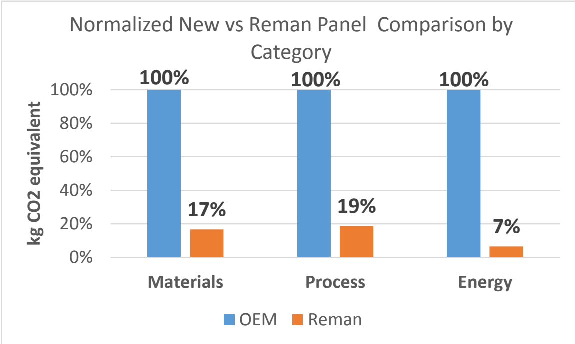
- The environmental impact for selected categories is significantly reduced for the Davies remanufactured office systems with a majority of the categories indicating reductions of greater than 80%. Only Ozone depletion saw the least reduction at 24% and 22% for reman 1 and reman 2 respectively.



Panel Component Remanufacturing compared to OEM (Combined life cycle method)

Analysis of the individual panel components of the defined office system reveals that remanufacturing of the panels significantly reduces the overall environmental impacts. The figures below represent the comparison of an OEM 65H x 48W panel to a remanufactured 65H x 48W panel (without indexing), for material use, processing and overall energy use. The comparison shows the remanufactured panel global warming impact for materials, process and energy is 17%, 19%, and 7% of the OEM respectively.





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1. Introduction

The Center of Excellence in Advanced & Sustainable Manufacturing (COE-ASM) at the Rochester Institute of Technology (RIT) was asked by Davies Office Inc. to compare the environmental impacts of Davies' remanufactured office workspace product system to an original equipment manufacturer (OEM) office workspace product system. The office workspace system is composed of divider panels, work surfaces and storage from a pedestal and lateral file. Quantities and styles of each may vary from system to system since there can be many different sized office systems. This system is fully defined in section 2.3.2. The OEM for the Avenir® office system upon which this study focuses is Steelcase, Incorporated. Davies remanufactures several major OEM office system product lines and offers highly customized options including ergonomic enhancements and modern styling options that may not be available from other office furniture providers.

Remanufacturing is a process that restores a worn and discarded product to a like-new condition so that it can be sold back into the market. The restoration is a high-quality process through which products are systematically disassembled, cleaned, and inspected for wear and/or degradation. Degraded or nonfunctional components are replaced, and the product is reassembled. By recovering and reusing viable product components, the materials and energy used to create the original product are preserved, allowing further value to be extracted from these original inputs.[1] Ultimately, by avoiding the need to reproduce those materials and components, remanufacturing serves to decrease the total embodied energy and material footprint of a product, reducing its overall environmental footprints.[1]

1.1 Life Cycle Assessment

The COE-ASM team investigated the environmental impacts of remanufacturing office workspace products by using established life cycle assessment (LCA) methodology. LCA is a tool used to quantify the environmental impacts associated with all phases of a product or process life from cradle-to-grave; from material extraction to manufacturing, transportation, use, and, ultimately, through end-of-life management. LCA helps identify environmental impacts by compiling an inventory of energy and material inputs and environmental releases, evaluating the potential impacts associated with those inputs and

[1] Hilton, B & Winnebeck, K (2011) Life Cycle Assessment Results: Energy and Environmental Impact comparison of the Hewlett Packard LaserJet !1338a (38A) Toner Cartridge and the Sustainable Earth by Staples™ Remanufactured Counterpart. http://www.staplesadvantage.com/sp/seb_lca/assets/pdf/Staples_38A_Toner_Cartridge_LCA_PUBLIC_Final_Report_9-13-12.pdf

releases, and then interpreting the results to help stakeholders make more informed decisions (reference ISO 14040:2006).

LCA results are useful for communicating the environmental impact of a product both internally and externally. Internally, LCA results enable identification of operations or materials that contribute significant environmental impacts, allowing opportunities for improvement to be targeted. Externally, LCA results can be used to validate marketing claims or compare the environmental impact of products between multiple manufacturers.

A Life Cycle Assessment is executed in four (4) distinct phases: (ISO 14040, 14044)

Step 1: Definition of goal and scope—identify the LCA's purpose, the products of study, and determine the system boundaries (i.e. what is and is not included in the study). See **Section 2**.

Step 2: Life-cycle inventory (LCI)—Quantify the energy and raw material inputs and environmental releases associated with each life cycle phase. See **Section 3.**

Step 3: Impact assessment (LCIA)—Assess impacts on human health and the environment. See **Section 4.**

Step 4: Result interpretation—Evaluate opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle. See **Section 5.**

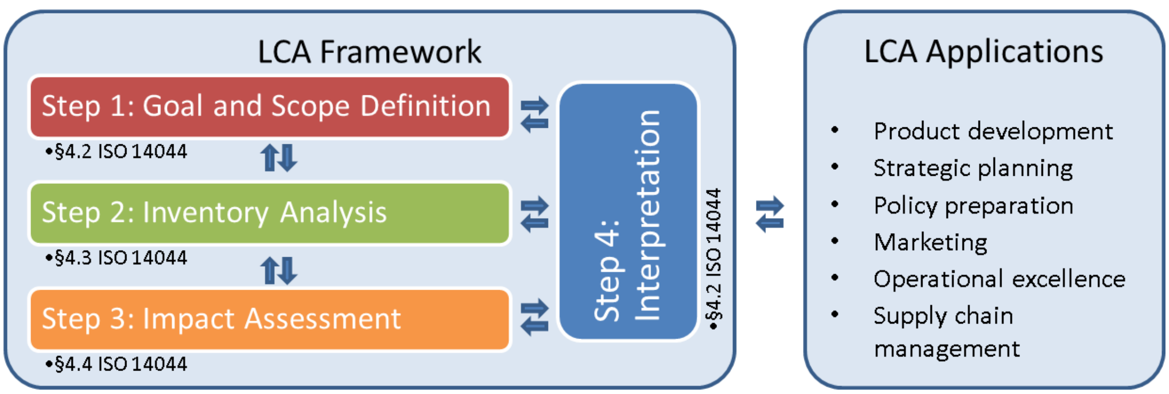

Figure 1: LCA Framework

1.2 Involved parties

Execution of this project involved technical staff from the Golisano Institute for Sustainability (GIS) at the Rochester Institute of Technology's (RIT) Center of Excellence in Advanced & Sustainable Manufacturing (COE-ASM), and staff at Davies Office Inc., (Davies). Davies granted access to its remanufacturing facility in Albany, NY to GIS researchers and provided the necessary primary data and material supplier contact information. GIS technical staff collected data and built representative models of the remanufacturing process using SimaPro 8 LCA software. These models were used to perform comparative analyses against OEM Steelcase products.

The OEM model relied on data from an LCA that was conducted on Steelcase office products which are similar to the ones analyzed during this study.[2] The OEM model was built utilizing the relevant material data, energy and production data provided in the Steelcase LCA. Material quantities in each component were derived from data collected at Davies. Material data quantities for panels was also acquired from a previous study conducted by the Center for Sustainable Production (CSP) at RIT.[3] All other process, energy and material data was derived from the Ecoinvent 3 materials and process database.

1.3 LCA practitioner

This project was completed by life cycle analysts Allen Luccitti and Dr. Mark Krystofik from the Golisano Institute for Sustainability (GIS) at the Rochester Institute of Technology (RIT) and supported by funding from the Center of Excellence in Advanced & Sustainable Manufacturing (COE-ASM) within GIS. Mr. Luccitti served as the primary analyst and Dr. Krystofik served an advisory role on the project.

Technical staff and faculty within GIS are certified life cycle assessment professionals, from the American Center for Life Cycle Assessment (ACLCA), and provide expertise and industry application of LCA methodologies. GIS conducts LCAs in accordance with ISO 14000 series standards for a broad range of industries, from the transportation sector to medical device manufacturers to office products. GIS may also function as an independent third-party critical reviewer, providing a non-biased, independent evaluation of the methodology and interpretation of others' LCA results. These LCA results are used by clients to make informed decisions for strategic planning, priority identification, and product or process design or redesign. In addition, the LCA process enables companies to identify opportunities to improve environmental performance, and thereby supports competitiveness in the green marketplace.

- Allen Luccitti, Senior Staff Engineer, Golisano Institute for Sustainability (GIS). Mr. Luccitti is a member of the Life Cycle Assessment team at GIS, assisting with ISO 14040 compliant LCA's and is a key resource for New York State Pollution Prevention Institute's (NYSP2I) Green Technology Acceleration Center and Sustainable Supply Chain and Technology Programs. Mr. Luccitti holds a B.S./M.E. in Mechanical Engineering from RIT.

[2] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005.

[3] CSP Report, Material Analysis of Davies Remanufactured Steelcase Avenir® and Steelcase Series 9000 Panels, 2011.

- Mark Krystofik, Ph.D., Senior Program Manager, Golisano Institute for Sustainability, Dr. Mark Krystofik is Senior Program Manager at the Golisano Institute for Sustainability (GIS) at Rochester Institute of Technology (RIT), where he is responsible for program management and research and development for the Center of Excellence in Advanced and Sustainable Manufacturing (COE-ASM). COE-ASM has a primary focus of assisting start-ups and established companies with research supporting the development of more sustainable products and processes, and is closely linked to RIT's involvement in the national Digital Manufacturing Design and Innovation Institute (DMDII). Prior to joining RIT, Dr. Krystofik's 20+ years of prior work experience in industry includes product development, design for manufacturing, manufacturing process development, strategic planning and operations management.

1.4 Critical Review

This life cycle assessment has been performed in accordance with ISO 14040:2006(E) *Environmental management—Life cycle assessment—Principles and framework*. A critical review was performed by an independent panel of experts and interested parties. Panel constituents were as follows:

- Kate Winnebeck, Chair—LCA Certified Professional, Senior Environmental Health & Safety Specialist, New York State Pollution Prevention institute (NYSP2I). Research focus includes life cycle assessment and modeling of health hazards and environmental impacts.

- Dr. Anahita Williamson, Panelist—Dr. Williamson has a strong background and extensive experience in the field of environmental engineering, including manufacturing process modification for improved material recovery and reuse, design for the environment and life-cycle assessment. She served as a senior engineer at Xerox Corporation where she assisted in implementing companywide sustainability and pollution prevention processes. Williamson led numerous teams at Xerox Corporation in defining environmental opportunities within processes/products by optimizing complex systems. She also has extensive experience in utilizing life-cycle assessment (LCA) methodology for evaluating the environmental performance of a process/product over its entire life-cycle and has performed multiple LCAs throughout her career. In 2012, Dr. Williamson was recognized with the Environmental Quality Award through the Environmental Protection Agency (EPA) and in 2013 with RIT's Principal Investigator Millionaire Award.

  Dr. Williamson is a Lean Six Sigma certified Greenbelt. She understands the importance of applying lean thinking when implementing industrial solutions. Dr. Williamson also has multiple peer-reviewed publications and has presented at numerous international and national conferences on topics including cleaner production, green engineering, the acceleration of green technologies and sustainable supply chain. Dr. Williamson holds a B.S. in Chemical Engineering and M.S. and Ph.D. in Civil and Environmental engineering, all from Clarkson University

- Thaddeus Owen, Panelist— Sr. Engineer, Sustainability, Herman Miller and Owner OTEC LLC

  Mr. Owen is Herman Miller's Sr. Sustainability Engineer and life cycle assessment leader. Since 2007, Mr. Owen has helped lead sustainable product design as part of Herman Miller's Sustainability team and has participated in drafting numerous national and international sustainability standards committees. He is passionate about health and wellness and works to create safe and healthy products including consulting to public and private companies on LCA, sustainability and greenhouse gas accounting.

  Mr. Owen holds a BS in Chemical Engineering from Clarkson University, an MS in Holistic Nutrition, Personal Training and Sports Nutrition Certifications and studies how the environment impacts human health and performance.

- Roy Green, Panelist— Mr. Green has life cycle assessment and SimaPro training through Earthshift and has conducted internal life cycle assessments in his role at HBF and Gunlocke. In addition, Mr. Green has served on the Business Institute Furniture Manufacturer Association (BIFMA) workgroups for product category rule (PCR) development and assisted in the development of the BIFMA PCR's for Office Furniture Workspace Products: UNCPC 3814 as well as assisted in the revision to BIFMA's PCR for Seating: UNCPC 3811 and BIFMA's PCR for Storage: UNCPC:3812

This Life Cycle Assessment Report is intended for public dissemination, may be disclosed to the public subject to the terms and conditions discussed in the Acknowledgements and Disclaimers section.

2. Goal and Scope Definition

2.1 Background

Founded in 1948 and headquartered in Albany, NY, Davies Office, Inc. is the largest independent office furniture remanufacturer in the United States. Davies receives various brands of office furniture products at the end of their useful lives from customers across the United States who seek to update their office space with newer styles and modern designs.

Davies offers a full line of office furniture products, including cubicles, workstations, panel systems, desks, tables, chairs, lateral files, and other workspace equipment. The company remanufactures major original equipment manufacturer (OEM) product lines, and offers customized options that may not be available from other office furniture providers. Davies is a full service provider offering both new, used, and refurbished products and innovative services that enable an affordable, more environmentally benign office furniture solution.

To position the LCA within existing and accepted framework, COE-ASM practitioners surveyed existing Product Category Rules (PCRs) for office furniture and workspace products. In accordance with the ISO 14025:2006 standard, the PCR is used to define the goal, scope, system boundary, functional unit, and impact methods used in life cycle assessments. A review of established guidelines in this area facilitated effective outlining and configuration of the study system.

There are three (3) existing PCRs relevant to office furniture products:

1. UNCPC 3812 & 3814: Other Furniture Used in Offices and Other Furniture, version 1.1, valid through December 14, 2017
2. BIFMA PCR for Storage: UNCPC 3812, valid through June 10, 2018, NSF International
3. BIFMA PCR for Office Furniture Workspace Products: UNCPC 3814, NSF International , valid through August 6, 2020

This LCA draws from the *BIFMA PCR for Office Furniture Workspace Products,* #3 above, which itself builds upon the preceding two outlines. This guideline works to better define the system boundary and functional unit, where other PCRs have purposefully left the functional unit definition open ended due to the diversity of the industry.[4] This new PCR provides a more defined functional unit that which will allow for a more repeatable analysis. This functional unit is defined as one square meter ($1m^2$) of workspace for a period of 10 years. This refers to the area occupied by the office product.

[4] National Center for Sustainability Standards (2014). *BIFMA PCR for Office Furniture Workspace Products: UNCPC 3814.* Web. Available from: http://www.nsf.org/newsroom_pdf/su_bifma_office_furniture_workspace_products_pcr.pdf

It is important to note that the BIFMA PCR was not intended for a comparative assessment, and not designed with remanufacturing in mind. Therefore, it was only used as a general guide for this study and not followed explicitly. Table 1 provides reference to areas of the PCR and if they were explicitly followed or used only as a guide.

PCR Category	General Category Metric/Description	Followed in Study (Y/N/ or Guide only)
Goal and Scope	The scope of the LCA shall conform to the ISO 14040 series (ISO 14044 Section 4.2.3.1) and be from cradle-to-grave.	Yes
Product Description	• Category of the product • Number of users • Area of physical floor space • Photo Image of product(s) • The features that the reference product includes in the arrangement / configuration of the LCA study	Yes
Functional Unit	The functional unit shall be one square meter ($1m^2$) of workspace for a period of 10 years	Guide Only
System Boundary	• Material acquisition and processing • Production • Distribution, storage, use • End of Life	Guide Only
Allocation Rules	Where possible, allocation should be avoided by dividing unit processes into two or more sub-processes (as specified in ISO 14044, Section 4.3.4, Allocation	Yes
Sensitivity Analysis	• Sensitivity analyses shall be performed when allocation is used • If proxy data representing more than 1% of the mass or energy of the system is used, a sensitivity analysis shall be performed using a range from half to twice the reference flow of the unit process	Guide Only
LCIA Method	• TRACI 2.1	Guide Only

Table 1: PCR Categories and application in study

2.2 Goal

The goal of this study is a comparative assertion of the environmental impacts of remanufactured Steelcase Avenir® office furniture workspace products made by Davies Office Furniture to equivalent OEM Steelcase Avenir® products through the use of a Life Cycle Assessment (LCA). This study utilized the LCA conducted on a Steelcase Answer (Answer) office products to develop an OEM model for the Steelcase Avenir® (Avenir®). Production process, energy, transportation, and component material content along with production location were used from that study. This data supplemented the primary data collected at Davies from the Steelcase Avenir® cores. A representative model for the OEM Avenir® was built with from this data for the comparison. Both the Avenir® and Answer are similar with respect to the office system products. The work surfaces for both use a particle board core with laminated covering and PVC edge. The panels both have a steel frame, insulation, fabric covering, and trim plates. The lateral file and pedestal are both primarily steel and powder coated. It is assumed that since the Answer and Avenir® both have similar component composition that the production process for the Answer will also be similar to the Avenir®.

Products of focus include a work surface, divider/wall panels, lateral file, and a storage pedestal. Davies hopes that results of this study will illustrate the environmental benefits of remanufacturing and the ability to bring these products to like or better than new conditions.[5] Results of this study are also intended to strengthen consumer confidence in a remanufactured product's value and quality as a whole.

This life cycle assessment has been performed in accordance with ISO standards 14040:2006(E) *Environmental Management—Life cycle assessment—Principles and framework*, and 14044:2006(E) *Environmental Management—Life cycle assessment—Requirements and guidelines.* Critical reviews have been performed by an independent panel of experts and interested parties.

The primary intended audience of this report is Davies Office. Office and furniture industry stakeholders, the educational and research community, and the general public may also benefit from these analyses. This life cycle assessment is intended for public dissemination, and may be disclosed to the public subject to the terms and conditions set forth in the Acknowledgements and Disclaimers section, and all sensitive

[5] R. T. Lund and W. M. Hauser, "Remanufacturing - an American perspective," Responsive Manufacturing - Green Manufacturing (ICRM 2010), 5th International Conference on, Ningbo, 2010, pp. 1-6. doi: 10.1049/cp.2010.0404

and confidential information such as intended only for internal use at Davies has been removed from this report.

2.3 Scope

This section defines the office system products included in the study, the system boundaries, functional unit and assessment methodology.

2.3.1 Product Description

This assessment focuses on a conventional office cubicle workspace system that includes a work surface, lateral file storage, storage pedestal, and a wall panel system. The OEM product brand and family identified for this assessment is the Steelcase Avenir®. Figure 2 illustrates the layout of a conventional office system in its assembled form. Figures 3 through 5 illustrate the constituent components of the workspace system.

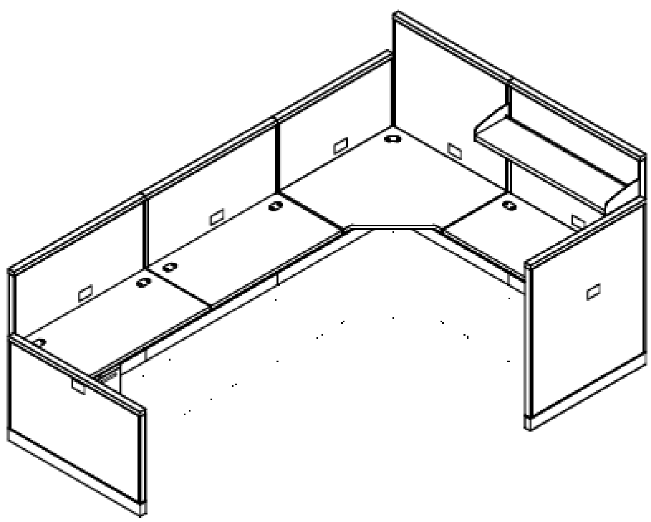

Figure 2: Typical Davies remanufactured Steelcase Avenir® office system

Work Surface

Work surfaces considered in this study consist of three (3) rectangular (straight) surfaces, as seen in the foreground of Figure 3, and one (1) corner work surface, seen in the background. These work surfaces are Steelcase Avenir® work surfaces recovered for remanufacturing from various companies. Both the OEM and Davies remanufactured work surface use a laminate covering over a particle board core, with poly vinyl chloride (PVC) edge banding. Davies can, not only match existing styles but offer additional styles that may not be available from the OEM.

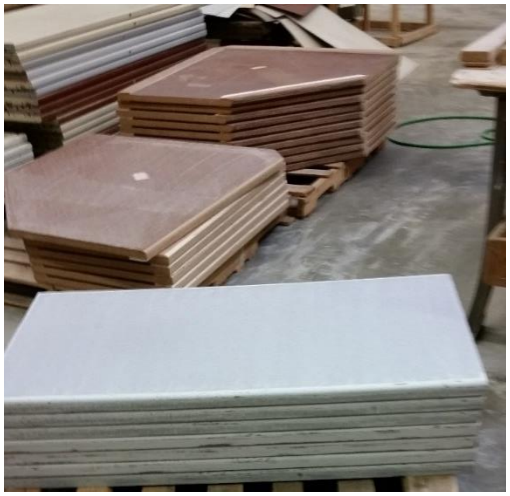

Figure 3: Steelcase Avenir® Work surface staging for remanufacture

Lateral File & Pedestal

This study considers one (1) of each type of file storage: a two- (2)-drawer lateral file and a three- (3)-drawer pedestal, both Steelcase Avenir®.

Figure 4: Steelcase Avenir® Pedestal ready for remanufacture

Panel

The defined office system contains seven (7) wall panels of four (four) different sizes, defined in Table 2.

Figure 5: Avenir® Panels after remanufacturing, ready for shipping

2.3.2 Functional Unit

The functional unit is defined as one (1) complete office furniture workspace system that will support one (1) intended worker with a service life of ten (10) years.

The functional unit is normalized to one square meter ($1m^2$) of occupied space. The occupied space of the office system being analyzed is measured to be $8.729m^2$. The analysis compared the Davies Avenir® office system to an equivalent OEM Avenir® layout with equal number of components. Davies offers a lifetime warranty on all remanufactured products, and could be expected that an individual remanufactured life cycle is greater than 10 years. Davies has indicated that their products can typically remain in service for greater than 10 years and that retirement of the office furniture is not due to failure but to changing needs and requirements of customers.[6] However, based on the PCR guideline, product service life is considered to be 10 years.

[6] Onsite meeting with Bill Davies and Mike Nguyen.

Modern office system components often contain electrical and communication functionalities such as task lights, electrical outlets and wiring, Ethernet and phone jacks and wiring and related hardware. These components and features are excluded from the current study due to the large variability of configurations.

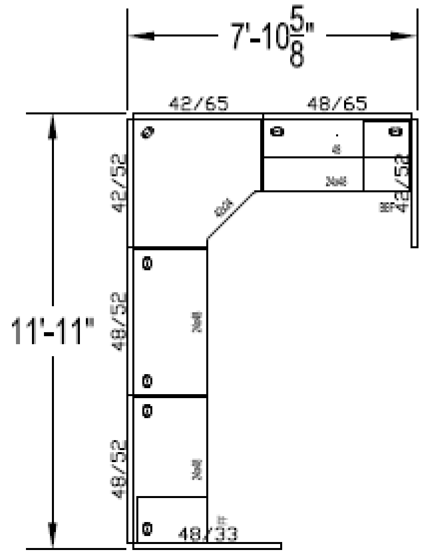

Figure 6: Davies Office Workspace layout

Even though the functional unit is defined as one (1) *complete* office workspace system, this assessment also considers comparisons of individual remanufactured system components to their OEM counterparts. This level of comparison enables a more complete understanding of the contribution from each component to total life cycle impacts.

Table 2 outlines the constituent elements of one (1) complete office system.

ITEM	DIMENSION (INCHES)	QUANTITY
WORK SURFACE	24W x 48L x 1.5T	3
WORK SURFACE	24W x 42L x 1.5T	1
PANEL	48w x 52h	2
PANEL	42W x 65H	1
PANEL	48W x 65H	1
PANEL	48w x 33h	1
PANEL	42W x 52H	2
PEDESTAL 3 DRAWER (BOX/BOX/FILE)	15W x 24D x 28H	1
LATERAL FILE 2 DRAWER (FILE/FILE)	36W x 18D x 28H	1

Table 2: Functional Unit Office System Components [7]

[7] Office system layout and configuration provided by Mike Nguyen at Davies for a specific customer/job.

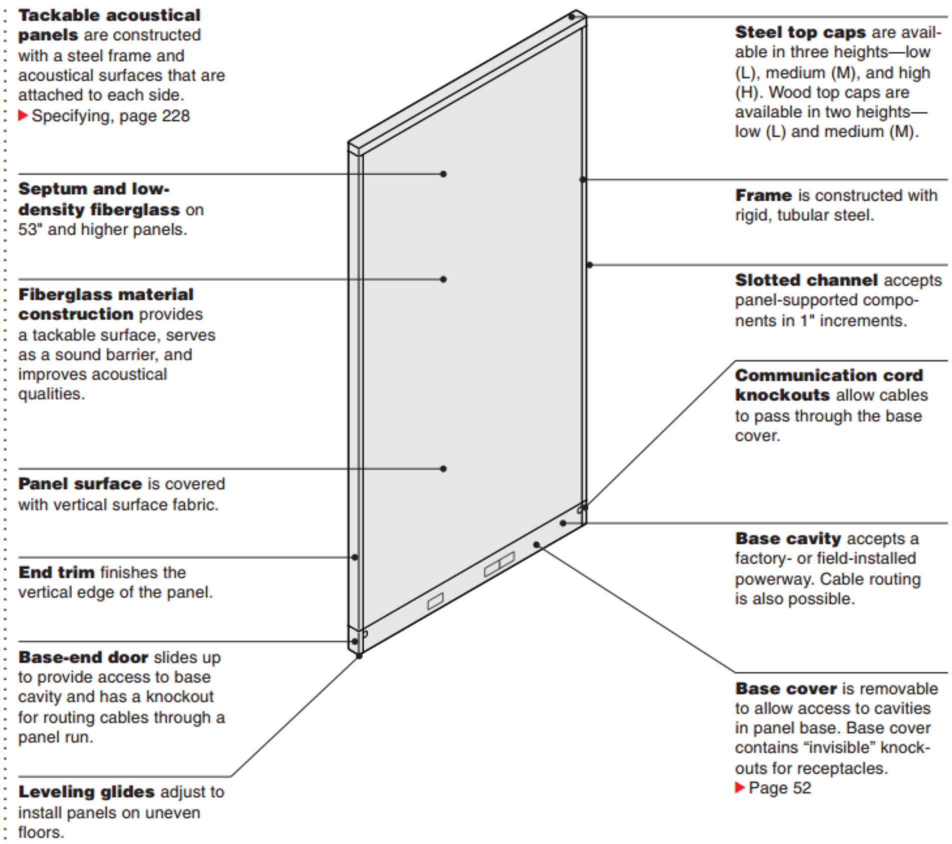

Figure 7: Wall panel [8]

[8] Avenir® Systems Furniture Specification guide, 2003 pp.9,219

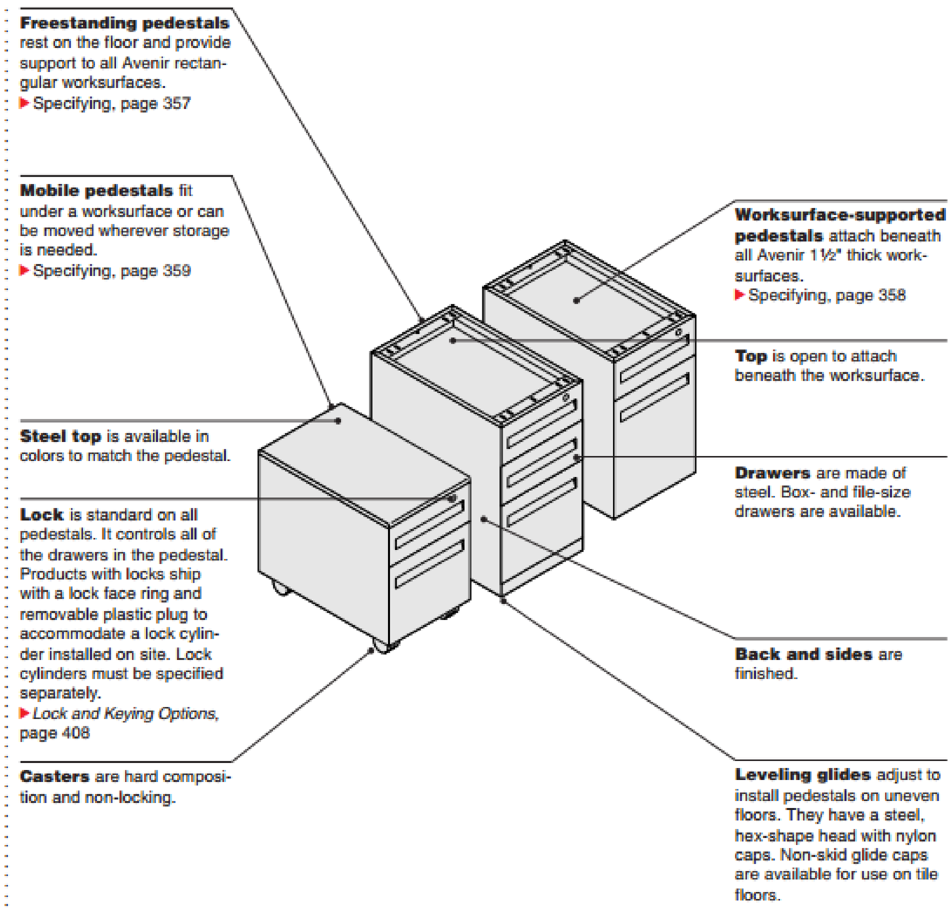

Figure 8: Storage pedestals [9]

[9] Avenir® Systems Furniture Specification guide, 2003 pp.153,351

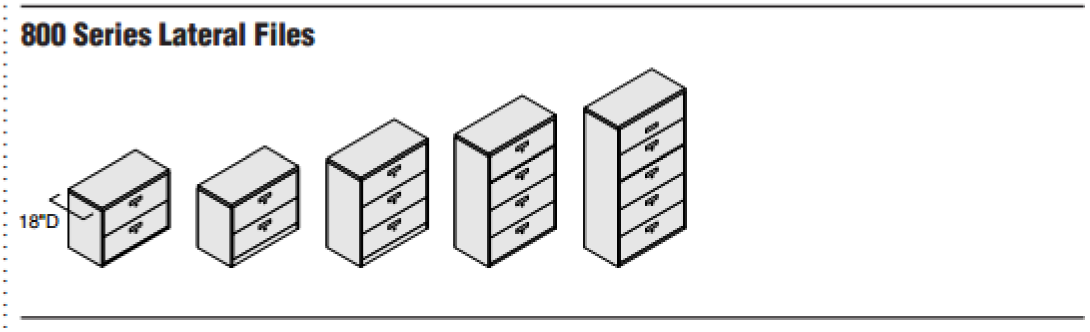

Figure 9: Lateral file unit[10]

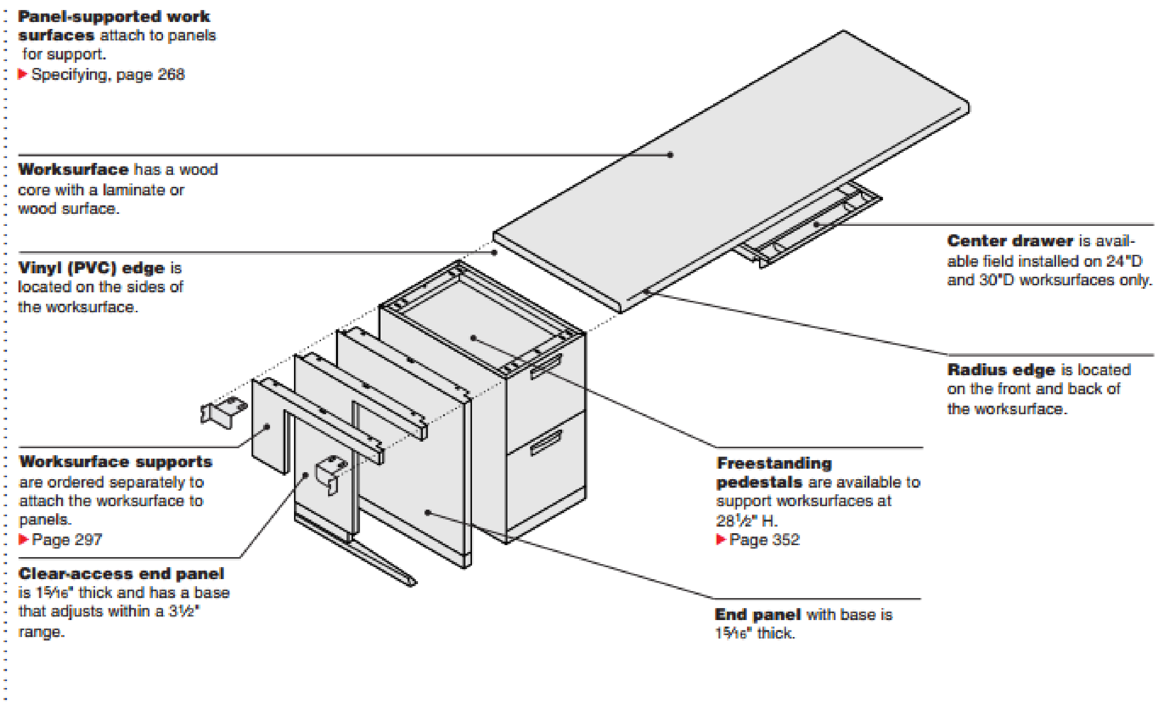

Figure 10: Work surface and supporting assembly[11]

[10] Avenir® Systems Furniture Specification guide, 2003 pp.153,351

[11] Avenir® Systems Furniture Specification guide, 2003 pp.71,267

2.3.3 System Boundary

The OEM Steelcase lifecycle is illustrated in Figure 11, starting with the production of the raw materials. The finished materials are then shipped to Steelcase for final production and assembly of the components. Once complete, the office system is shipped to the customer for use. At the end of the office systems useful life it is sent to the municipal solid waste stream (MSW) where some materials that can be separated go through recycling. The current model assumes only the steel material in the panel frame and file storage go to recycling, all other materials are sent to landfill.

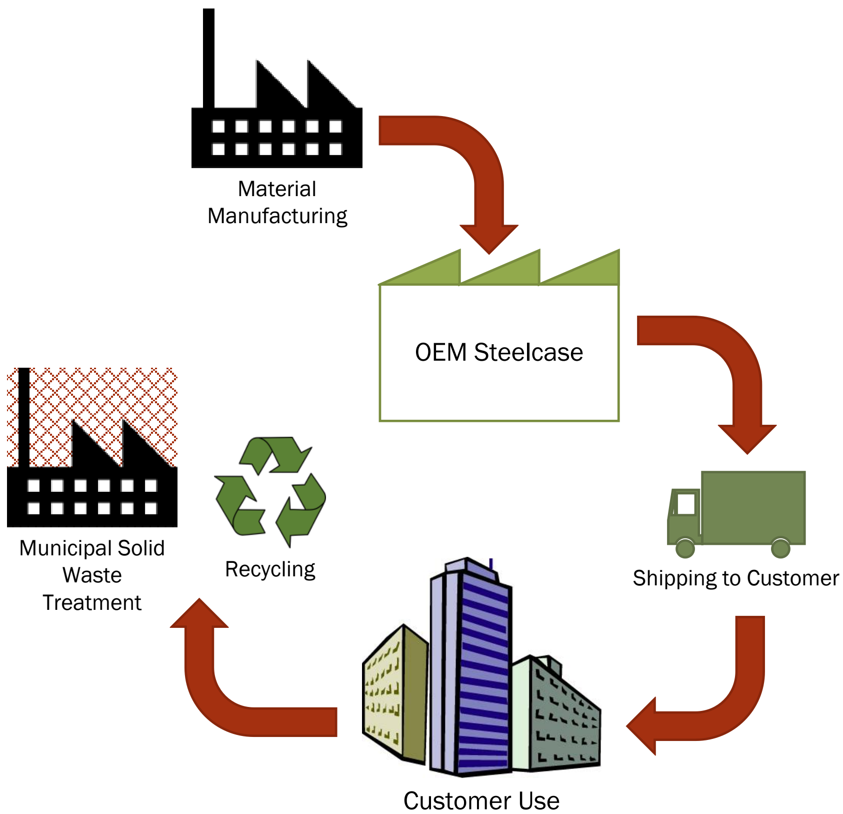

Figure 11: Steelcase OEM Life Cycle

The individual component process flows were adopted from (Dietz 2005) study and is assumed that these processes are representative of the Avenir® process flow. Portions of the Steelcase Answer process flows may vary from Avenir® based on the Avenir® material content. The Answer work surface had steel legs and a process for the production of these legs is included in the Answer process flow, while the Avenir® does not have these support legs. Variations between the Answer and Avenir® are noted in each flow diagram, Figure 12, Figure 13, and Figure 14.

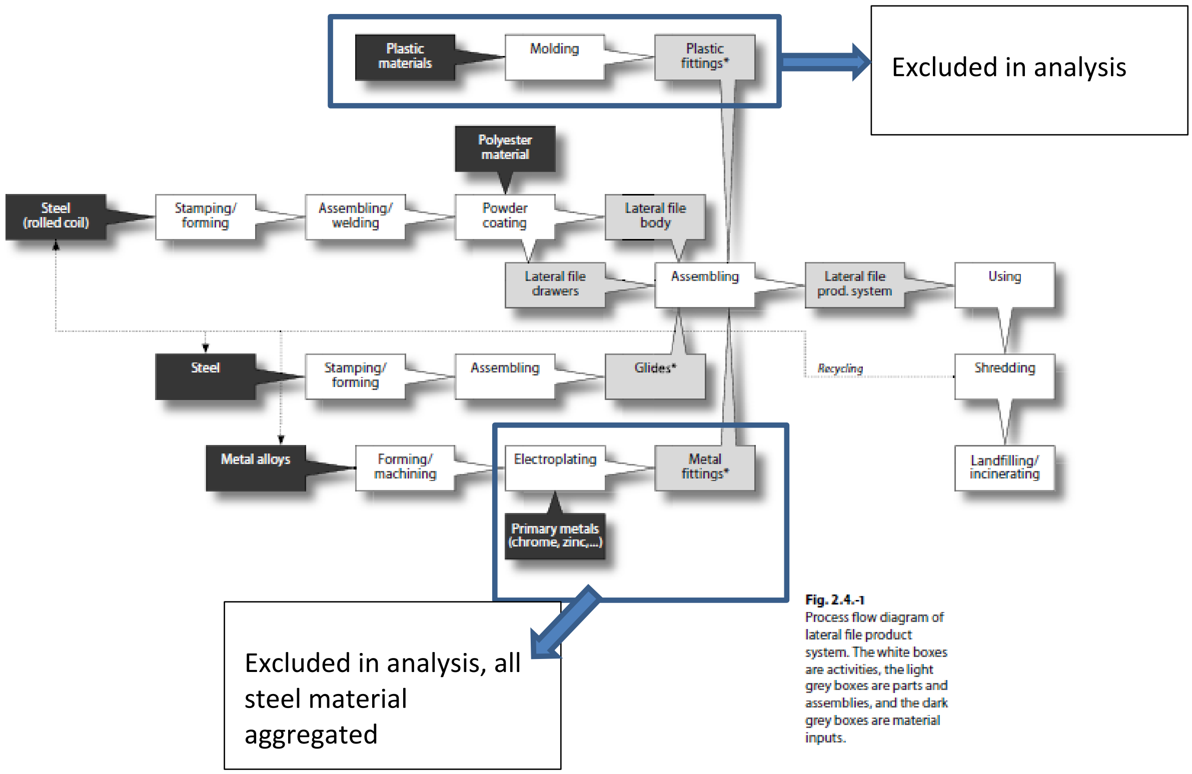

Figure 12: Steelcase Answer Lateral File Process Flow[12]

The lateral file process flow illustrated in Figure 12 for the Steelcase Answer. It can be assumed that this is representative of the Avenir® process. Eliminated from the evaluation are the plastic materials and electroplating.

[12] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005

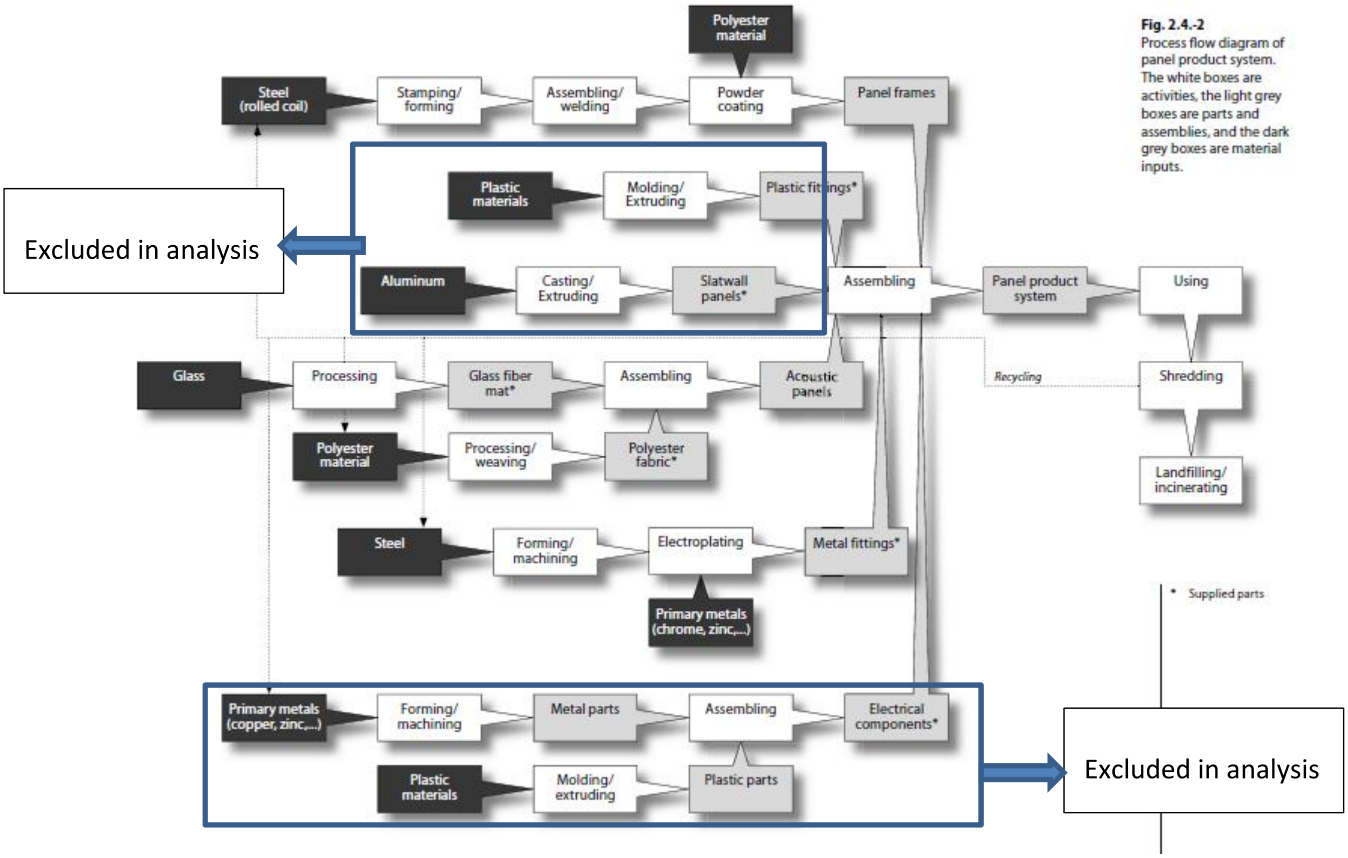

Figure 13: Steelcase Answer Panel Process Flow[13]

The Steelcase Answer panel process flow illustrated in Figure 13 is assumed to be representative of the Avenir® process, excluding the specific components highlighted. The electrical and plastic components were excluded along with the aluminum slatwall which were not observed in the Avenir®.

[13] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005

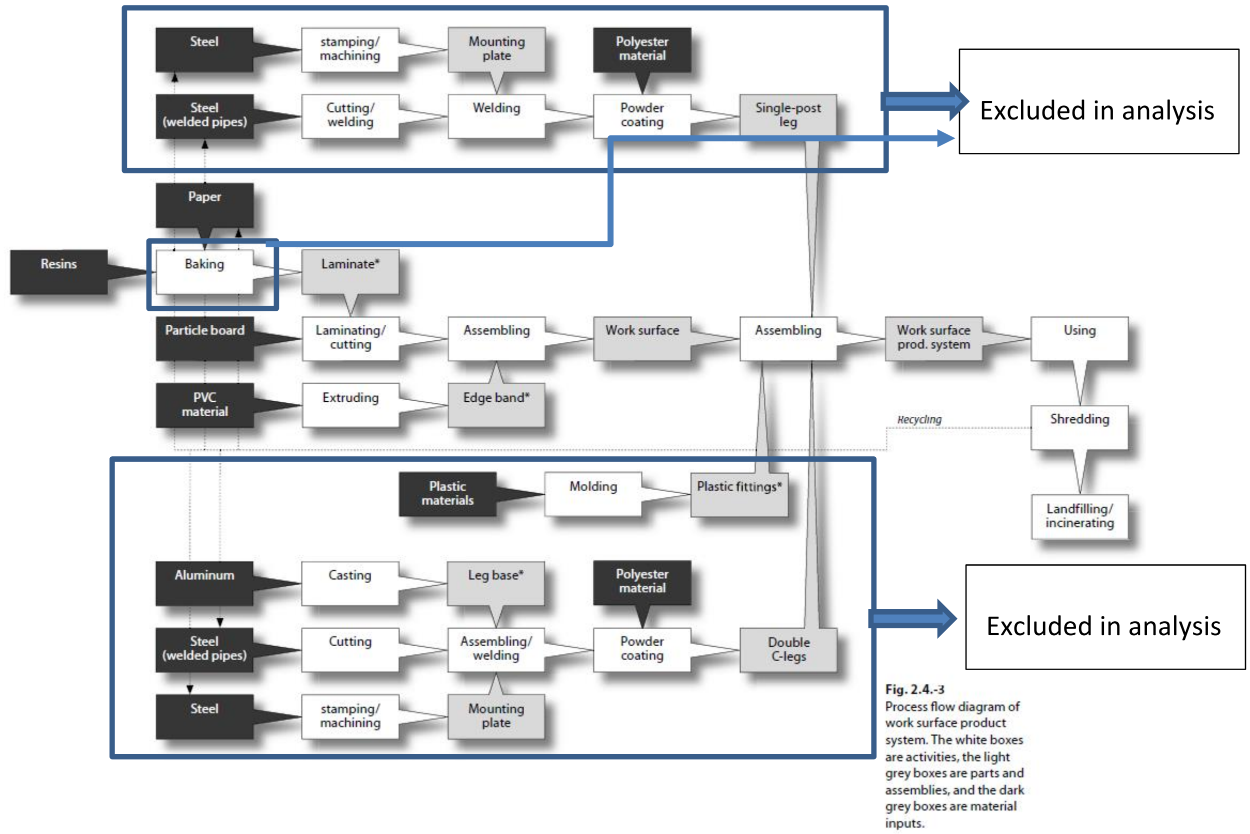

Figure 14: Steelcase Answer Work Surface Process Flow[14]

The Steelcase Answer Work Surface process flow illustrated in Figure 14 is assumed to be representative of the Avenir® process flow, excluding the highlighted materials and processes. The Avenir® did not have the support legs and hardware that are part of the Answer work surface.

The Davies remanufactured office workspace product life cycle was modeled as a closed loop system. In this system, Davies recovers the office workspace products to be remanufactured directly from customers. Equipment is then shipped back directly to the Davies facility in Albany, NY, where Davies

[14] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005

remanufactures them to like- or better-than-new condition.[15] Davies is able to upgrade the office system components with current power and communication functionality that may not have been available previously. The remanufactured office system is then transported back to the customer for installation and use. This is illustrated in Figure 15 below.

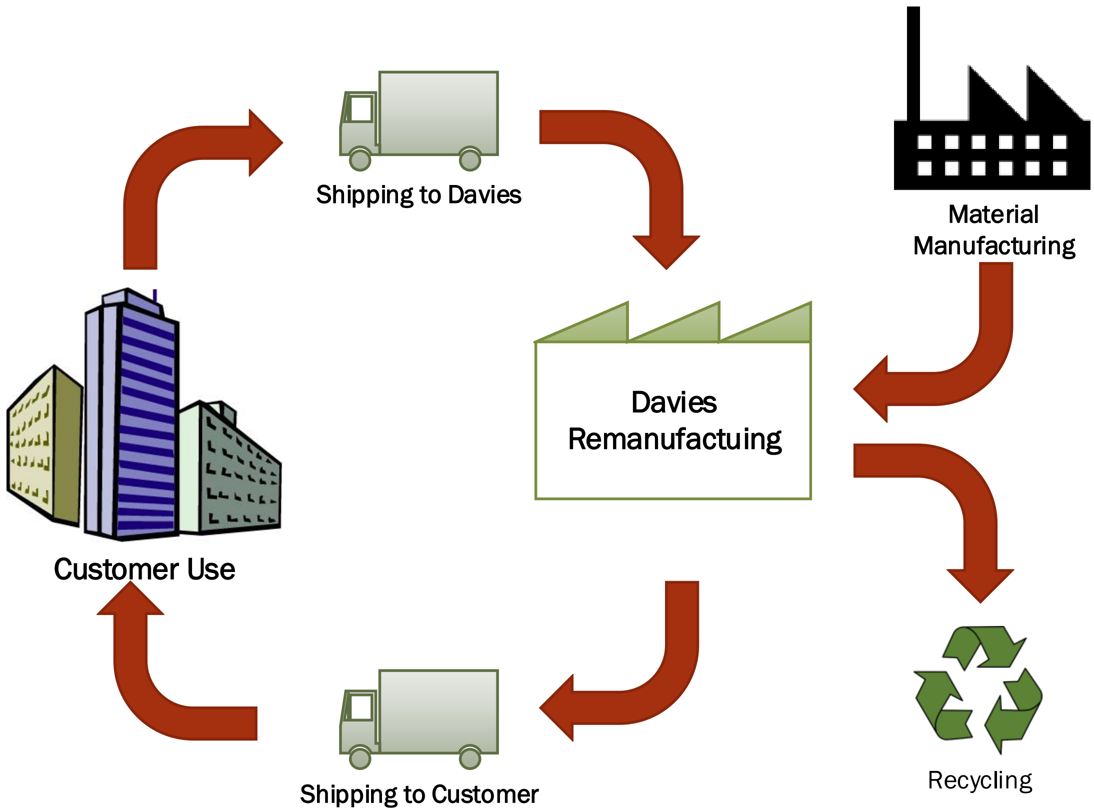

Figure 15: Davies Closed Loop Remanufacturing Process

This study considers the complete life cycle of the remanufactured office system from "cradle" to "grave" wherein the "cradle" is defined as the point at which an OEM office system is retired (at the end of its first useful life) and acquired by Davies, and the "grave" is the point at which the remanufactured system is retired at the end of its own useful life. The full life cycle inventory is available in Appendix C.

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[15] R. T. Lund and W. M. Hauser, "Remanufacturing - an American perspective," *Responsive Manufacturing - Green Manufacturing (ICRM 2010), 5th International Conference on*, Ningbo, 2010, pp. 1-6. doi: 10.1049/cp.2010.0404

2.3.4 Boundary Exclusions

Because office workspace equipment does not itself consume energy or create emissions during its use, use phase impacts of the OEM and remanufactured office workspace systems are assumed to be equivalent, and are therefore excluded from the boundary of consideration. Any additional features added to the OEM or remanufactured office system such as task lighting or electrical outlets are assumed outside the scope of this analysis and therefore excluded. Data for the maintenance, upkeep, and warranty repair of the office system—which are assumed to be the only potentially impactful contributors to this phase—are not readily available for either system. Irrespective of this data scarcity, these impacts are also considered to be equivalent between the two systems, as the remanufactured system is intended to achieve equivalent life cycle performance to the OEM and would therefore require effectively equivalent levels of maintenance and repair. A study of the remanufacturing of automotive engines to original equipment specifications, show they have equivalent performance and durability to the OEM engines.[16] An office system in comparison with an automotive engine is more passive with minimal moving parts such as the file drawers, and will not be subjected to the same type of use. Thus it can be assumed that the remanufactured office system will easily meet OEM performance requirements considering it will not be subjected to harsh operational conditions. As a result, these use phase impacts are collectively excluded from this study.

The remanufacturing of the office components does not include or account for all of the processes required for the OEM system components. One significant process difference between the OEM and reman is that reman does not require steel processing into the final components. This processing, which includes metal stamping and forming, would be for the creation of the panel frames, file and pedestal housing and drawers.

2.3.5 Cutoff Criteria

A cut-off criterion has been applied in this analysis where any materials or energy that constitute less than one (1) percent of the total mass or energy may be excluded from this analysis. Any data that is neglected or rejected outside of the system boundaries is justified with individual explanations in Section 3.2: Assumptions and Limitations. No environmental cutoffs are applied.

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[16] Smith, V. M. and Keoleian, G. A. (2004), The Value of Remanufactured Engines: Life-Cycle Environmental and Economic Perspectives. Journal of Industrial Ecology, 8: 193–221. doi:10.1162/1088198041269463

2.3.6 Limitations

The results of this assessment should not be considered the only source of environmental information with respect to the identified products and processes. As common with all LCA studies, there are limits to data quality, especially for the production of upstream materials, where information may vary widely between company, location, and data source. The LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risk. As a result, this LCA represents only the Davies remanufactured Steelcase Avenir® office system described in the preceding sections of this report. Other remanufactured office products and the processes by which they are made may have environmental impacts not discussed here.

The lack of current primary OEM Steelcase Avenir® data is one limitation that is important to note. The OEM Steelcase LCA referenced in this study is approximately 11 years old at the time of this report, therefore current conditions and practices for the OEM may result in impacts that are greater or less than reported in the OEM study. This can be attributed to improved process efficiencies, change in manufacturing location, or change in materials used.

Limitation ID	Limitation Description
1	OEM Avenir® production data not readily available, production data for Steelcase Answer office products used from (Dietz 2005) Study
2	OEM process and manufacturing data approximately 11 years old, improvements in efficiency, and changes in manufacturing location may result in variation of the impacts
3	Current OEM packaging materials and practices are unknown
4	Production energy mix may be different due to changes in manufacturing location

Table 3: Limitations

2.3.7 Allocation Procedures

No manufacturing operations are shared between the defined office workspace system in this study and other products not considered in this study; allocation of process inputs and resultant impacts are therefore not items of concern. The processes identified were only observed for the components in this study, even though Davies does remanufacture other products none were remanufactured at that time, and therefore the total process intensity can be allocated solely to the remanufactured products in this study.

Overhead energy was allocated to a specific manufacturing process within the facility. Davies has three utility service areas: (1) main production and warehouse; (2) showroom, metal manufacturing, offices; and (3) a retail outlet center. An overhead energy rate for each area was determined based on billed energy use for one billing cycle in August of 2015, and the combined square footage of each area. Table 4 outlines each area and the associated overhead for electricity and natural gas.

Utility Service Area	Total sqft	Electricity Overhead kWh/sqft/hr	Natural Gas Overhead kWh/sqft/hr
Main Production/Warehouse	205,883	0.00043	8.24E-05
Showroom/Metal/Office	40,468	0.00072	2.89E-03
Outlet	6,647	0.00098	NA

Table 4: Overhead Rates

Overhead values are allocated based on the percentage of total operational area occupied and the amount of time it takes to complete each process. Process time values for each system component were measured in detailed evaluations of ongoing remanufacturing processes to ensure relevance and accuracy.

OEM energy allocation is defined in section 3.1.2.

2.3.8 Software Tools

SimaPro 8.0.4.26 modeling software was used to calculate, analyze, and compare the environmental impacts of each system. SimaPro is a commercially available life cycle assessment tool that integrates peer-reviewed data and environmental impact methodologies to assist with modeling the environmental impact of a life cycle. This software was used in conjunction with the contemporary and peer-reviewed Ecoinvent 3 material and process database. Entries within this database reflect the real-world life cycle impacts of a material or process.

2.3.9 Life cycle impact assessment methodology

This project used the ReCiPe version 1.11, 2014 midpoint+ method, and Cumulative Energy Demand 1.09 impact assessment library.

2.4 Modeling Methodology

2.4.1 Overview

New office furniture systems introduced to the market reflect the design needs and style preferences of present business users. These preferences are, however, inevitably susceptible to variation over time. Accordingly, Davies current remanufacturing methods reflect a notable shift in customer design preferences. Older office equipment styles (e.g., prior to year 2000) featured tall panel dividers in a cubicle design. Contemporary office culture, however, encourages a more open and collaborative workspace. As a result, much of Davies' focus is on the resizing (size reduction) of office panels, lateral files, and storage units by cutting them down; a process Davies refers to as "indexing."[17]

Davies has been able to capitalize on this shift to smaller office systems and shorter panel heights by implementing the indexing practice. We introduce the term "adaptive remanufacturing" to describe this situation, and define adaptive remanufacturing as the process of adapting a core normally used to remanufacture a like product to be used to remanufacture a similar product. As an example, Davies is able to utilize panel divider cores that measure 65"H x 48"W to produce panel dividers of 52"H x 48"W that include additional features, such as a frosted glass panel to allow more light to the office cubicle than the original panel. Although Davies primarily resizes cores, adaptive manufacturing may be a more generally applicable term and practice, including instances where surplus cores intended for a given product may be modified and made suitable as a core for a similar but non-identical product. The remanufacturing scenarios in this study include circumstances both with and without indexing for the panel dividers. Although Davies also resizes work surfaces, storage cabinets, and pedestals, as well as reconfiguring drawer layouts based on customer requirements, this study does not consider indexed units of those product types in order to preserve the uniformity of the functional unit.

2.4.2 OEM Office System

This analysis considers only the Steelcase Avenir® OEM office system, as this was the primary product family offered at Davies during this assessment. A previous study conducted through the Center for Sustainable Systems at the University of Michigan analyzed the life cycle of the Steelcase Answer office system.[18] This study provided detail for materials, manufacturing processes and transportation of the office products. This data was used to build the OEM Avenir® model in SimaPro for comparison to the remanufactured system.

The OEM Steelcase Answer and Avenir® office systems are similar in regards to the major components contained within each system. Both utilize a file storage system constructed primarily of steel. The divider panels are both composed of similar materials and the physical configuration is similar as well. Both systems utilize a particle board work surface covered with a laminate. The only major difference between the work surfaces is the Answer uses support legs constructed of steel with additional hardware, where

[17] Meeting at Davies, comments by Bill Davies and Mike Nguyen

[18] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005.

the Avenir® does not. This study is able to segregate the components and materials of interest from ones that are not the same, for comparative assertions.

2.4.3 Davies Remanufactured System

The Davies remanufacturing process begins at the field disassembly and return shipping of old office systems from customer locations to Davies processing facilities in Albany, New York. Upon arrival, Davies segregates the various components into four (4) categories—work surfaces, storage cabinets, panels, and hardware—and sends them either to remanufacturing operations or to storage (Figure 16). During this initial processing stage, Davies conducts a preliminary assessment of incoming product quality to separate products that are unusable due to irreparable damage or age. Davies does not explicitly track the number of components that do not meet the quality for remanufacture. Davies did provide an estimate as to what they typically see for each component. They are typically able to repair most damaged items. They did indicate that the panel fiberglass tack board and the work surface core are two items that can require replacement. Davies provided estimates as to how often they replace those items. Davies indicated that one in one hundred work surfaces might require replacement, while one in twenty tack boards may require replacement. These estimates are normalized on a per product basis in the model and the new material and scrap are counted accordingly. For the work surface and tack board, new materials are used in those instances where replacement is required.

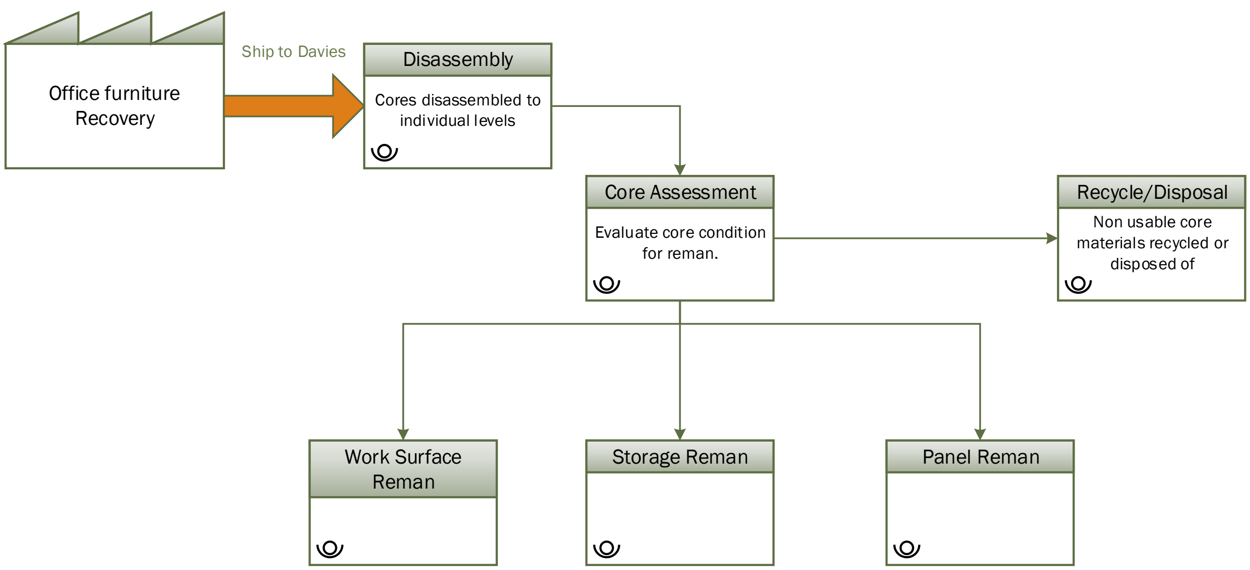

Figure 16: Remanufacturing Intake Process

After evaluation and staging, components proceed through the remanufacturing process in accordance with unique customer specifications. Each component process varies depending on the initial condition of the component and the customer's requirements. Customers typically define upholstery material and color specifications. Many of the processes at Davies are executed manually or utilize small electric or pneumatic hand tools.[19]

Work Surface Remanufacturing

The work surface process, illustrated in Figure 17, begins with the removal of hardware and evaluation of the core. New laminate and edging are added to the work surface; old edging is removed and discarded, however old laminate may be layered over without stripping off the previous layers. If several layers of laminate accumulate due to previous remanufacturing, they are sanded off and replaced with a fresh layer in order to meet thickness specifications required for compatibility with the rest of the system. Table 5 shows the material reuse rates for the work surface, which accounts for the rejected material that was not suitable for reuse. Note that reuse rates for original laminate are 0%; this reflects the practice of adding new laminate regardless of existing laminate condition. Existing laminate is often left on the work surface core, but, when covered, is not the topmost functional layer, and is therefore not considered to be reused. Several remanufacturing cycles of a work surface will inevitably increase the overall thickness due to the multiple laminate layers. When this occurs, Davies will conduct a more substantial sanding operation to reduce the work surface thickness by removing the additional laminate layers. This does not mean, however, that all layers are removed, rather enough material is removed to meet the thickness requirement.

Work Surface

Component Description	Reuse Yield 1st Reuse	Reuse Yield 2nd Reuse
Work Surface Core	99%	99%
Laminate	0%	0%
PVC Edge band	0%	0%

Table 5: Material Recovery

[19] Site visit observation during data collection.

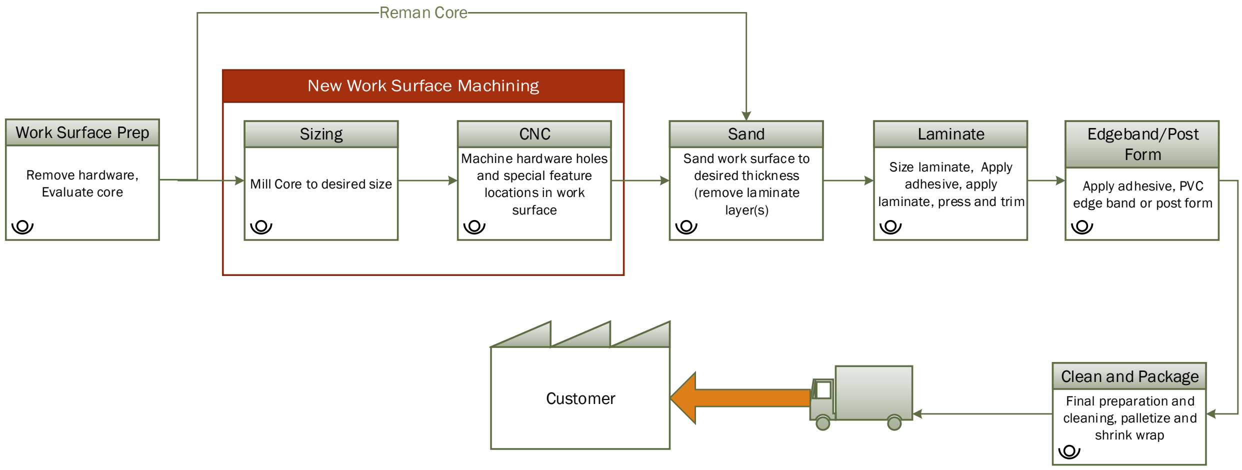

Figure 17: Work surface remanufacturing process

Waste from the work surface process consists of old PVC edgeband, trimmings from the laminate, and dust from sanding operations. During instances where the work surface requires replacement, the old work surface will be scrapped. There will also potentially be scrap from the cutting and forming of a new work surface from particle board.

Panel Remanufacturing

Panels may follow two (2) different pathways; standard remanufacturing or Indexing (Figure 18). The indexing process resizes panel structures to meet specific customer requirements. This process is unique to Davies, and creates a competitive advantage by offering customizable component configurations often not available from the OEM. Materials removed in the indexing process are discarded primarily to recycling; those that are not recyclable are disposed of in municipal solid waste. Table 6 indicates material reuse rates in initial and subsequent remanufacturing cycles, which takes into consideration the fall out of panel materials that do not meet quality standards and cannot be reused.

Panel

Component Description	Reuse Yield 1st Reuse	Reuse Yield 2nd Reuse
Panel Frame with legs	100%	100%
Top Cap	100%	100%
side rails	0%	0%
snap on frame	100%	100%
Fabric Skin	0%	0%
Tack Board	95%	95%

Panel

Component Description	Reuse Yield 1st Reuse	Reuse Yield 2nd Reuse
Acoustical Filler	100%	100%
Chipboard Divider	100%	100%

Table 6: Panel Material Reuse

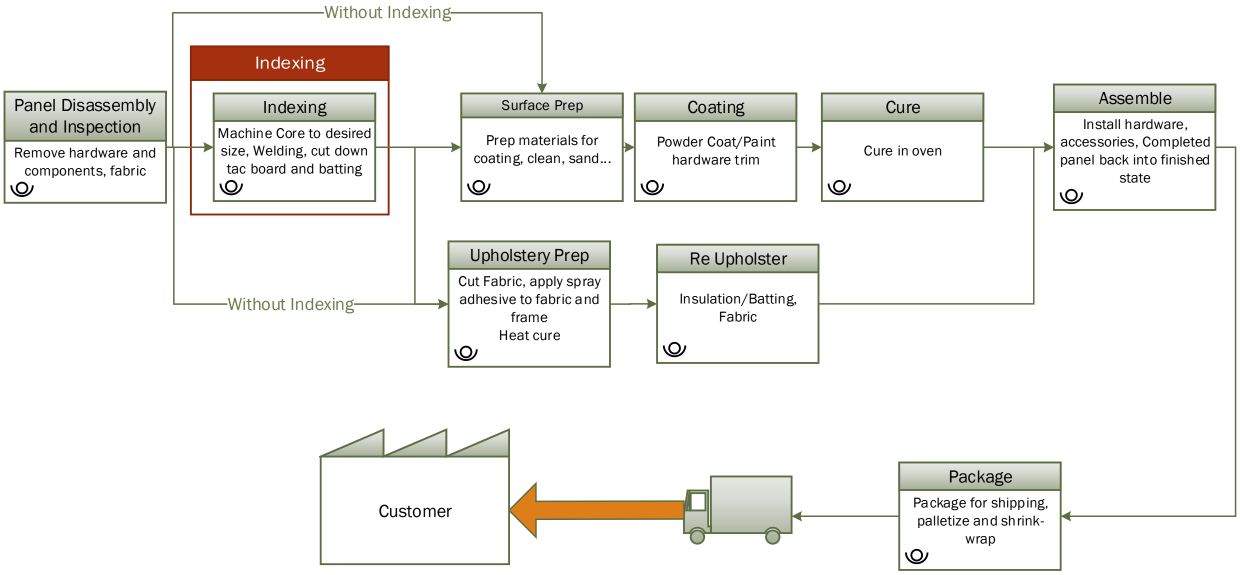

Figure 18: Panel remanufacturing process

Waste from the panel process includes old fabric covering, steel side rails from the OEM that are replaced with PVC side rails and recycled. For the scenario where panels are indexed, the steel frame material removed is recycled, and the tack board, and acoustical batting scrap from indexing are scrapped as well. Tack board is also scrapped when it does not meet the quality requirements for reuse and replaced with new material.

File/Pedestal Remanufacturing

Lateral file and pedestal units may also follow either of two (2) paths (Figure 19). Indexing is generally used only for taller files and other storage units, while the pedestal and two- (2) drawer lateral file units are a standard height designed specifically to fit under the work surface. This study does not consider indexing of the file or storage due to the rarity of its occurrence. This omission allows life cycle models to more accurately represent typical products. All components within file and pedestal units are saved and reused (Table 7), Davies indicated that they are able to reuse all storage and that there is no fall out.

File/Pedestal

Component Description	Reuse Yield 1st Reuse	Reuse Yield 2nd Reuse
Core/shell	100%	100%
Drawers	100%	100%

Table 7: File/Pedestal Material Reuse

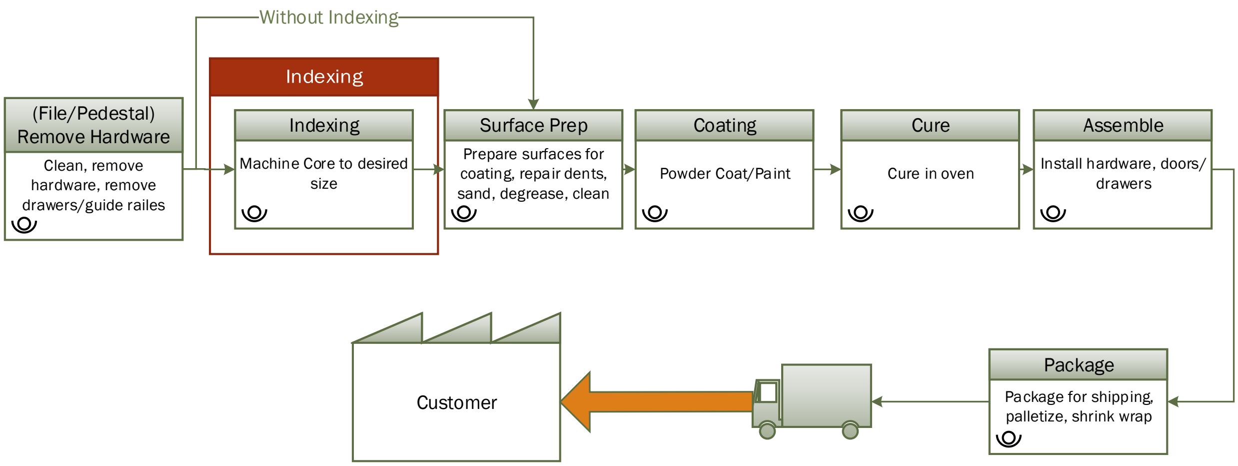

Figure 19: File and Pedestal Remanufacturing

Waste from the file and pedestal remanufacturing process are primarily from the powder coating process. Powder coating over spray is collected and disposed of. Heat from the curing oven may also be considered an emission.

The scenarios modeled in this study for OEM and Reman have the same quantity of components and same layout illustrated in Figure 2 and Figure 6. In this study three consecutive life cycles are modeled, the OEM, Reman 1 and Reman 2. The OEM life cycle starts with all panels at 65 inches high, which are sized (indexed) down during the first remanufacturing cycle to the sizes indicated in Table 2. The Reman 2 life cycle assumes all panels are sized accordingly and no indexing occurs. The components and office system were modeled with two types of scenarios, independent and combined. The combined life cycle model assumes reman would not exist if not for the OEM therefore OEM impacts are included. For each life cycle the impacts are aggregated and divided based on the total number of life cycles the system experienced as illustrated in Figure 20. The independent life cycle compares the OEM life cycle directly with the reman life cycle.

Illustrated in Figure 21 is the method for determining the life cycle impacts for the combined model. Each life cycle starts with the OEM and ends with final EOL. The combined life cycle method takes the burden from each life cycle and distributes it equally across each life cycle within that scenario.

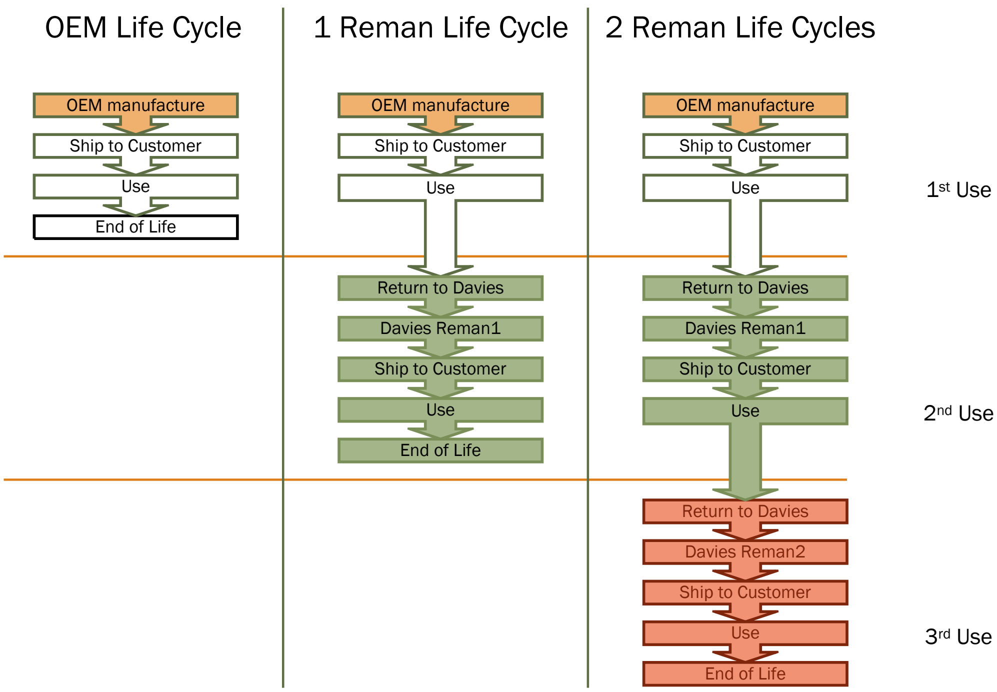

Figure 20: Combined Life Cycle Model

The combined life cycle method applies the burden of the OEM material use and the credit for recycling at the end of life across all life cycles, illustrated in Figure 21. This method averages the aggregated impacts of the products across the number of life cycles the products have endured.

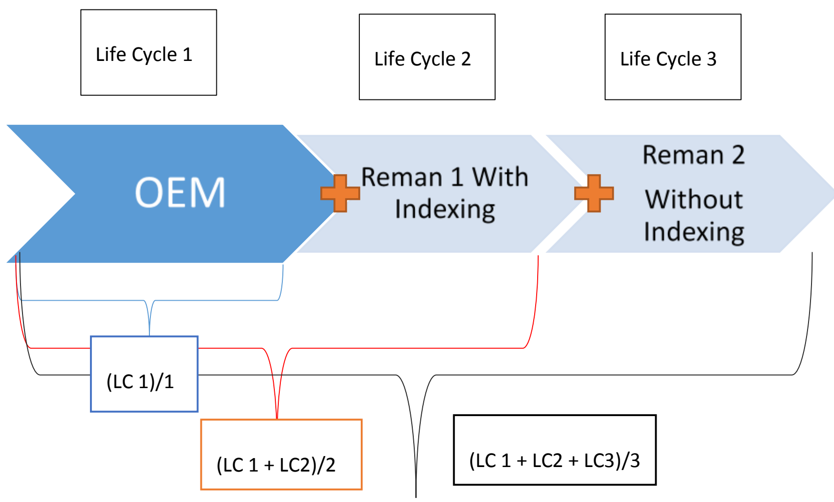

Figure 21: Combined Life Cycle Model Calculation

3. Life Cycle Inventory

3.1 Inventory Data

3.1.1 Material

Life cycle impacts are calculated based on the mass of each constituent material used in production. Mass data for each component material was measured directly at the remanufacturing facility and supported by previous material analyses performed at Davies. Material types were determined by product/material data sheets, literature research, and COE-ASM experience and expert knowledge. At the request of COE-ASM, Davies provided part and material replacement rates for each of the three (3) main office system components. COE-ASM staff translated materials lists from OEM and remanufactured office systems to corresponding material types modeled in the Ecoinvent 3 database. In the event a material was not available in the database, a surrogate material model was either chosen or built from the combination of other available material models that would most closely represent the original. One example of a surrogate would be the tack board which is comprised of a pressed fiberglass, Table 8. Since there are no finished materials that represent the tack board in the Ecoinvent 3 database, one was made using raw fiberglass material and a binding resin. Both the OEM and Davies use a water based resin for the contact adhesive. Specific data for the OEM resin was not available in the OEM LCA. Davies uses a 3M Fastbond 30NF with the composition illustrated in Figure 22. For the composition in SimaPro, water content is assumed to be a median of the range at 45%. Polychloroprene was modeled at the median of 35% using synthetic rubber, which serves as the base material. The rosin polymer with phenol was modeled with phenolic resin at the maximum 10%, which has a formaldehyde constituent. Glycerol esters of rosin acids was modeled at the maximum 10% using esters of versatic acid. Any ingredients that were within a range of 1.0 % or less were assumed inconsequential and not included. This same composition was used for the OEM model as well, since primary data was lacking.

Ingredient	C.A.S. No.	% by Wt
WATER	7732-18-5	30 - 60
POLYCHLOROPRENE	9010-98-4	25 - 45
ROSIN, POLYMER WITH PHENOL	68083-03-4	5 - 10
GLYCEROL ESTERS OF ROSIN ACIDS	8050-31-5	5 - 10
TOLUENE	108-88-3	1 - 3
METHYL ALCOHOL	67-56-1	1 - 3
ZINC OXIDE	1314-13-2	1 - 2
ROSIN	8050-09-7	< 0.7
POTASSIUM HYDROXIDE	1310-58-3	< 0.5
2,2'-METHYLENEBIS[6-TERT-BUTYL-P-CRESOL]	119-47-1	< 0.4
NITROGEN	7727-37-9	<= 0.01

Figure 22: Binding Resin Composition for 3M Fastbond 30NF (Used by Davies) [20]

[20] Material Safety Data sheet 3M™ Fastbond™ 30NF Cylinder Spray Contact Adhesive, Neutral 08/09/10

Material selections in the Ecoinvent 3 database include the energy required to manufacture individual constituent materials. However, the manufacturing processes required to make each *component* were identified through analysis of OEM and Davies manufacturing systems and translated to processes within the Ecoinvent database.

Table 8, Table 9, and Table 10 indicate the material content for each component by size and mass. The panels have five different sizes, shown in Table 8, and indicates the material type, quantity and mass.

			Panel Material Weight (each) kg				
Component	**Quantity**	**Material**	**48w x 52h**	**42W x 65H**	**48W x 65H**	**48w x 33h**	**42W x 52H**
Panel Frame with legs	1	Steel	11.19	11.98	12.65	9.07	10.52
Top Cap	1	Steel	0.98	0.86	0.98	0.98	0.86
side rails	2	Vinyl	0.28	0.35	0.35	0.18	0.28
snap on frame	2	Steel	2.08	2.23	2.35	1.69	1.96
Fabric Skin	2	Fabric (Polyester/PET Based)	0.42	0.46	0.52	0.27	0.37
Tack Board	2	Pressed Fiberglass	1.26	1.37	1.57	0.80	1.10
Acoustical Filler	2	Cellulose fiber batting	0.57	0.62	0.71	0.36	0.50
Chipboard Divider	1	Cardboard	1.14	1.25	1.43	0.72	1.00

Table 8: Panel Material Content

The work surface material in Table 9, indicates an increase in laminate material content. At Davies a new layer of laminate is added on top of the existing layer, thus increasing the overall laminate content. The OEM PVC edge band mass is slightly less than the reman edge band. The OEM edge band removed for the work surface core was weighed directly, and is less than the replacement banding.

		48x24 Straight kg			42x24 Corner kg		
Component Material Description	**Quantity**	**OEM /Core**	**Reman 1**	**Reman 2**	**OEM/Core**	**Reman 1**	**Reman 2**
Particle Board	1	21.9	21.9	21.9	30.5	30.5	30.5
Laminate	1	1	2	3	1.49	2.98	4.47
PVC Edge band	1	0.048	0.060	0.060	0.048	0.060	0.060
Spray adhesive	1	0.110	0.110	0.110	0.110	0.110	0.110

Table 9: Work Surface Material Content

The lateral file and pedestal, Table 10, are predominately comprised of steel.

Component Material Description	Quantity	Material	OEM/Core (kg)	Reman 1 & 2 (kg)
Lateral file	1	Steel	49.18	49.18
Pedestal	1	Steel	31.10	31.10

Table 10: File and Pedestal Material Content

During the indexing process of the panels at Davies, the removed materials are sent to either recycling or waste treatment. Table 11 indicates the mass of the materials removed from panels that started at 65 inches high, panel width is not altered.

	Indexed material to recycling and waste treatment (kg)			
Material	**48w x 52h**	**42W x 65H**	**48w x 33h**	**42W x 52H**
Steel Total	2.00	1.04	4.91	3.04
Chipboard total	0.29	0.18	0.70	0.43
Tac board total	0.63	0.39	1.55	0.94
Batting total	0.28	0.18	0.70	0.43

Table 11: Indexed Material from Panels

3.1.2 Energy

OEM manufacturing energy is all of the energy required to gather materials, manufacture, and assemble the final office system components, along with a constant overhead energy value. Overhead energy is the energy that indirectly supports the overall manufacturing facility; that is, energy for lighting, heating, cooling, and ventilation. The OEM manufacturing energy was derived from the (Dietz 2005) study and normalized to a kilowatt-hour per kilogram of component mass (kWh/kg) for each of the three (3) components.[21] (Dietz 2005) estimates manufacturing energy use at the Steelcase Company for general machinery, powder coating, welding, compressed air, and miscellaneous overhead. Powder coating and welding process models are available through the Ecoinvent 3 database and can be modeled and

[21] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005.

calculated explicitly; these processes were therefore excluded from intensity calculations since the OEM study provided data for welding and powder coating rates. The OEM energy intensity embody the remaining processes not represented in the Ecoinvent 3 database for the manufacture of the components, and applied as the US average energy mix within the component models. The OEM LCA provides data for energy use at Steelcase for component manufacturing and the ratios by various processes. Table 12 shows the energy intensity for each OEM component.

	Panel	Work Surface	File
Energy Intensity kWh/kg	0.119	0.156	0.116

Table 12: OEM Energy Intensity

Table 2-7: Manufacturing Equipment Operating Requirements; source: Bernhard thesis except (a) and (b); (a) source: (GE 2003), (b) source (Bookshar 2001)

Equipment	Electricity, kWh/hr	Compr. Air, cf/hr	Cool. Water, gal/hr
CNC laser cutter (steel)	27	1,500	
CNC router (wood)	19.8	1,500	
Conveyor band (per motor)	0.4		
Cut and edge band	30	5	
Drilling (steel)	0.959		
Dowel inserter	5	2	
Electric hand tools	0.4		
Finishing	120	15	
Hot-laminating press (wood)	31.8	1,020	
Hot-melt station (fabric)	18.6	2,100	
Hydr. press, large	38	5,000	13,200
Hydr. press, medium	28	2,500	12,000
Hydr. Press, avg.	33	3,750	12,600
Linear drive system (a)	0.963		
Mech. Press, large	20.9	2,750	
Mech. press, medium	17.5	1,560	
Mech. press, small	6.65	420	
Mech. Press, avg.	15.0	1,580	
MIG-welder	56.9	684	360
Pneumatic hand tools (b)	0	1,460	
Powder coating line	642	8,820	
Projection welder	0	0	0
Roller press	25.2	1,500	
Sanding	25	10	
Splicer	5	2	
Spot welder	95		250
Stretch foiler (packaging)	5	300	
Table saw	10	2	
Tenoner	20	2	

Figure 23: Equipment Energy Rates from OEM LCA Applied to Davies Reman Processes[22]

[22] Spitzley, D. V., Dietz, B. A., & Keoleian, G. A. (2006). Life-Cycle Assessment of Office Furniture Products. Center for Sustainable Systems, School of Natural Resources and Environment, University of Michigan, Ann Arbor. Available at: http://css.snre.umich.edu/css_doc/CSS06-11.pdf.

Remanufacturing energy is all of the energy, including overhead, required to disassemble, inspect, clean, replace, and reassemble office system components. Davies provided a list of equipment used during the remanufacturing process at the request of COE-ASM. During an onsite visit, COE-ASM staff collected additional equipment data and conducted time studies for each remanufacturing process. These values were combined with process energy consumption rates (energy per time) presented by (Dietz 2005) to estimate process energy use at Davies.[23] Energy rates for certain pieces of equipment used at Davies were derived from values reported in Figure 23, which are assumed to be industry average rates.

Both OEM manufacturing and Davies remanufacturing processes were mapped to representative Ecoinvent 3 processes models whenever possible. For example, there are representative processes in Ecoinvent 3 for welding and powder coating, which are therefore used, while a process for small hand tools is not explicitly defined in Ecoinvent, therefore one had to be created.

Manufacturing energy was modeled as the average US medium voltage at the grid for both the OEM and Davies, from the Ecoinvent unit process.

3.1.3 Packaging

Material and process models for OEM packaging are derived from (Dietz 2005) analysis of Steelcase Answer office products, which are assumed to share the same packaging with the Steelcase Avenir® system. Current Steelcase packaging practices favor use of recycled and recyclable materials, reducing use of virgin sources.[24] The Dietz study indicated that a total of 7kg of cardboard was used for the work surface and panel combined, 5.8kg of it was applied to the panel. Additionally, 0.8kg of LDPE film is also applied to an individual panel per the study.

Models for Davies product packaging are based on material measurement and analysis performed during onsite assessment and discussions with Davies staff. Davies packaging consists of cardboard, LDPE foam and LLDPE stretch wrap for packaging of components.[25] The LDPE foam and cardboard are used primarily to protect component edges and surfaces from contact. The stretch wrap is used to secure multiple components to a pallet.

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[23] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005.

[24] Steelcase Corporate Sustainability Report, 2014. https://www.steelcase.com/content/uploads/2014/11/Steelcase-Inc_2014-Corporate-Sustainability-Report_Web.pdf

[25] Onsite assessment and data provided by Davies.

3.1.4 Transportation

End-of-life (EOL) office systems designated for remanufacturing are transported from the customer to Davies by truck; the remanufactured office system will then be returned by truck to the same location.

Davies has customers across the United States, and thus transports products to and from customers at varying distances. In effort to maintain consistency throughout the life cycle model, a nominal transportation distance is derived from the top ten (10) states which had the most total invoiced dollars, which represents 80% of Davies annual sales. Travel distance from Davies to a central location in each of these states was measured and weighted based on total sales for each state. Using this methodology, a travel distance of 638 miles (1027 km) was calculated and used as the nominal one-way product transport distance. A complete OEM office system would be retrieved by Davies and transported 638 miles back to their remanufacturing facility. Once remanufactured they would once again transport the office system 638 miles back to the customer.

This study also considers transportation effects from external materials purchased by Davies to support remanufacturing. This includes transport for replacement upholstery and PVC side rail components used on the panels, as well as the PVC edge banding and laminates used on work surfaces.

OEM transportation is based on results reported by (Dietz 2005) for each component. The average travel distance from Steelcase to customer is approximately 191 miles (308 km).[26] Average EOL transportation distance is approximately 25.5 miles (41 km).

3.1.5 End-of-Life (EOL) Management

The end-of-life is the final disposition of materials and components of the office system at the end of its useful life. This study analyzes several EOL pathways, which are the municipal solid waste stream (MSW), material recycling, and a combination of both. Davies disassembles all components at their facility, any materials that cannot be reused are automatically recycled, if possible. Since the (Dietz 2005) LCA is dated, some of the EOL routes for non-remanufactured OEM office components covered in that study may not fully reflect current practices. This study assumes that 100% of the steel contained within the panel and

[26] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005

file/pedestal storage will be recycled. The remaining panel materials are sent to landfill. 100% of the work surface is assumed to go through the MSW waste stream.

3.2 Assumptions and Limitations

While much of the data was provided by Davies or from literature, some assumptions were required to complete the assessment.

Assumption ID	Assumption Description	Justification
1	Hardware, such as fasteners or connecting brackets were excluded from the analysis	Hardware falls below the cutoff criteria and would have equivalent impacts for OEM and remanufacturing
2	Consumables at Davies excluded	Consumable materials not already accounted for in an Ecoinvent unit process were excluded as they would fall below the cutoff criteria of 1%. This includes grinding and sanding discs, and fillers used to repair material surfaces. One (1) out of every 15 work surfaces may require filler repair, using approximately one (1) ounce of filler material, which is below the cutoff based on mass.
3	Use phase excluded from the analysis	It is assumed that the OEM and Reman will experience similar use, and due to the relatively static nature of the components, with the exception of the drawers on the file and pedestal, use will not be significant. Even though use is within the boundary it is excluded from the analysis since it is assumed similar, therefore this phase of the life cycle is ignored.
4	OEM Manufacturing Process for Steelcase Answer similar to Avenir®	It is assumed that since the OEM Steelcase Answer office system components analyzed in the Dietz 2005 study are similar to the Steel case Avenir®, that the processes for the Answer will also be similar to the Avenir®.
5	Second reman life cycle does not have indexing	It is assumed that component resizing (indexing) occurs during the first reman life cycle and not the second.
6	Scrap material and end of life disposition	It is assumed that steel removed during indexing from panel frames is recycled in the combined life cycle method. Also it is assumed 100% of the steel frames and steel file cabinet at end of life are recycled while all other materials go through the MSW stream.
7	Packaging materials and process	Material and process models for OEM packaging are derived from (Dietz 2005) analysis of Steelcase Answer office products, which are assumed to share the same packaging with the Steelcase Avenir® system.
8	Component process flow	The individual component process flows were adopted from (Dietz 2005) study and is assumed that these processes are representative of the Avenir® process flow. Portions of the Steelcase Answer process flows may vary from Avenir® based on the Avenir® material content.
9	OEM Work Surface process flow	The OEM process flow in figure 14, adopted from (Dietz 2005) is assumed to be representative of the Avenir® process flow excluding the materials and processes highlighted
10	OEM Panel process flow	The OEM process flow in figure 13, adopted from (Dietz 2005), is assumed to be representative of the Avenir® process flow excluding the materials and processes highlighted. The electrical and plastic components were

		excluded along with the aluminum slatwall which were not observed in the Avenir®
Assumption ID	**Assumption Description**	**Justification**
11	OEM File process flow	The OEM process flow in figure 12, adopted from (Dietz 2005), is assumed to be representative of the Avenir® process flow excluding the materials and processes highlighted. Eliminated from the evaluation are the plastic materials and electroplating.
12	Reman Transportation	It is assumed that the office system Davies receives for remanufacture will be returned to the same location after.
13	OEM Transportation	OEM transportation derived from the adopted from the (Dietz 2005) study for the Steelcase Answer and assumed to be similar to Avenir®

Table 13: LCA assumptions and justification

3.3 Secondary Data: Life Cycle Assessment Databases

All material and process data provided by Davies and Davies' suppliers were mapped to equivalent representative materials and processes included in the Ecoinvent 3.1 database compiled October 2014. Materials or processes not defined in the database are represented with material or process models that most closely reflect the original. Individual materials were used to build the panel fabric, fiberglass tack board and the acoustical batting, from the Ecoinvent database and based on manufacturer documentation and specifications of the material content. For the tack board, acoustical batting, and adhesive only the material constituents in the specified proportions were used to make those material, there is no processing for their production due to the lack of available processes in Ecoinvent. The fabric also used specified material constituents in their proportions, and the material processing used the process for fleece production, since the material is produced from PET plastic. The work surface laminate only consisted of the material constituents since there was not a representative process for the production or available data. For this analysis, SimaPro 8.0.4.26 LCA software was used to translate the life cycle inventory data into environmental impact.

Ecoinvent 3.1[27] data is used to provide secondary data in SimaPro. Ecoinvent data is compiled from peer reviewed life cycle assessments and peer reviewed data sets. Most Ecoinvent data is collected in Sweden and Europe and represents the industry average in these countries. Select data points, such as the average

[27] http://www.ecoinvent.ch/

energy mix, have been collected for the United States and are included in the database. Ecoinvent data is one of the most complete datasets of all life cycle databases commercially available. It is assumed that operations in Europe and the United States are world class, with similar energy usage profiles and production wastes and emissions. It is assumed that Ecoinvent data is representative of US operations. US data was used where available in the Ecoinvent database. Additional information on Ecoinvent data can be found in section 4.2.

3.4 Data Quality

This section outlines the data quality requirements, as specified by ISO 14044 section 4.2.3.6.2.

3.4.1 Consistency, Precision, and Completeness

Consistency considers how uniformly the study methodology is applied to the various components of the analysis. The methodologies, modeling parameters, and assumptions outlined above were applied to all configurations and scenarios equivalently. The OEM model is based upon the data collected from the OEM core at Davies prior to remanufacturing. Additional process and energy data was used from a previous LCA study. Materials and processes were built in SimaPro from the Ecoinvent 3 database and applied in the same manner to both the OEM and Reman models.

Precision is a measure of the variability of data values within each data category. Because only one data set was available for each configuration, there is no alternate point of reference to which precision can be measured.

Completeness measures the portion of used data collected through primary means for each category in a unit process. Actual material and process data was collected for the remanufactured office products. Where possible, Davies provided facility energy use, material usage, and EOL scrap values for their operations. OEM material quantities were measured at Davies for the OEM cores on hand.

3.4.2 Temporal, geographic, and technological representativeness

Temporal representativeness describes the age of data and the minimum length of time for which data was collected. All primary data from Davies was collected in August 2015, and represents current products and practices. Remanufacturing data, including part weights, materials, scrap, and process energy were determined by conducting time studies through the completion of each individual process.

Geographic representativeness describes the geographic area from which unit process data is collected for the study. The impacts of Davies energy use are based on expected impacts from the average U.S. electrical generation grid as modeled by the Ecoinvent 3 database. The US average was chosen to eliminate location bias as an additional variable.

Technological representativeness describes how well the dataset used to develop the LCA model represents the true technological characteristics of the system. Actual materials were identified through material suppliers, literature search, material analysis, and through Davies staff experience and expertise. These materials were translated to equivalent models available in the Ecoinvent database. Where data for a specific material was not available, surrogate materials were used and documented as an assumption.

3.4.3 Representativeness

Representativeness is an assessment of how the dataset used in the LCA model reflects the true system. Component bill of materials (BOM) and remanufacturing process data were either provided by Davies or collected during an onsite study of each process. In this sense, data used in this study is derived directly from the real-world system itself for the Davies remanufacturing model. The OEM model relied on some data presented in a previously conducted study, which may not be representative. Since the cores evaluated at Davies are Steelcase Avenir®, the material content for the OEM is representative. The study relies on OEM manufacturing and energy data from the study conducted in 2005 (Dietz 2005).

3.4.4 Reproducibility

LCA modeling was performed and documented such that this LCA may be reproduced by another LCA practitioner. This report contains all life cycle inventory data and all assumptions used to calculate the environmental impact of each configuration.

3.4.5 Source of Data

The data source for all data is provided in Appendix A and B.

3.4.6 Data Uncertainty

Variability exists in process inputs and outputs. This variability is built into Ecoinvent unit processes as a distribution around the data sources where available. The goal of uncertainty analysis is to understand how uncertainty in the data and assumptions may affect the LCA results. Uncertainty analysis was not performed.

SimaPro was used to perform Monte Carlo analyses of the scenarios in order to understand how data uncertainty affects the results of the life cycle assessments. Each scenario was run 1,000 times at 95% confidence. The uncertainty comparison was made between the OEM office system and the first remanufactured office system using the ReCiPe Midpoint method. Results of the comparison show that only the Natural Land Transformation category has 16.2% uncertainty that the reman office system will have a greater impact than the OEM. The table of results can be seen in Appendix D: Uncertainty Results.

4. Life Cycle Impact Assessment

Life Cycle Impact Assessment (LCIA) is the phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. The purpose of this impact assessment is thus to interpret the life cycle GHG emissions and resource consumption inventory for both the OEM and Davies systems. These impacts are communicated in terms of indicators for the Areas of Protection: human health, ecosystem health, and natural resources.

In accordance with the ISO 14044 process, the LCIA proceeds through four (4) steps, the first two of which are compulsory, and the last two optional.[28] This study incorporates all four (4) LCIA steps in the interest of completeness. The steps are as follows:

- **Classification:** all substance elementary flows from the life cycle inventory (e.g. resource consumption, emissions into air, etc.) are assigned to impact categories based on the types of complications to which each is related.
- **Characterization:** all substances are multiplied by a factor which reflects their relative contribution to the impact category. For example, the characterization factor of CO_2 for climate change is one (1), whereas the characterization factor for methane—which is known to be several times more potent as a GHG than CO_2—is more than 20. This characterization factor therefore is used to reflect that methane has a higher potential contribution to climate change than carbon dioxide.
- **Normalization (optional):** the quantified impact is compared to a certain reference value; for example, the average environmental impact of a one person during one year in a stated geographic context.
- **Weighting (optional):** different value choices are given to impact categories to generate a single score of relative importance. Weighting may be useful as an internal communication tool when designing complex products and when trade-off situations occur when comparing alternative products. Weighting should not be used for public dissemination of comparative assertions.

4.1 Life Cycle Impact Assessment Methods

Impact assessment calculations are performed using SimaPro version 8.0.4.26 LCA software. This software has multiple native impact assessment methods. The methods chosen for this analysis are detailed below.

[28] European Commission, 2010 European Commission, Joint Research Centre, Institute for Environment and Sustainability, ILCD Handbook: Analysing of Existing Environmental Impact Assessment Methodologies for Use in Life Cycle Assessment, European Union (2010).

4.1.1 Recipe v1.11 (2014)

One of the main impact assessment methods used in this analysis is the internationally recognized ReCiPe v1.11 (2014) life cycle impact assessment methodology.

The ReCiPe methodology was selected for its comprehensive spectrum of impact categories. The ReCiPe methodology uses a combination problem-oriented (midpoint) and damage-oriented (endpoint) approach. It links eighteen (18) midpoint impact categories to three (3) damage categories: human health, ecosystem quality, and resources. The eighteen (18) impact categories addressed in ReCiPe are shown in Table 14 below.

Impact category	abbr	Indicator Name	unit	Characterization factor	abbr	Unit
climate change	CC	infra-red radiative forcing	$W \times yr/m^2$	global warming potential	GWP	kg (CO_2 to air)
ozone depletion	OD	stratospheric ozone concentration	ppt×yr	ozone depletion potential	ODP	kg (CFC-11 to air)
terrestrial acidification	TA	base saturation	$yr \times m^2$	terrestrial acidification potential	TAP	kg (SO_2 to air)
freshwater eutrophication	FE	phosphorus concentration	$yr \times kg/m^3$	freshwater eutrophication potential	FEP	kg (P to freshwater)
marine eutrophication	ME	nitrogen concentration	$yr \times kg/m^3$	marine eutrophication potential	MEP	kg (N to freshwater)
human toxicity	HT	hazard-weighted dose	–	human toxicity potential	HTP	kg (14DCB to urban air)
photochemical oxidant formation	POF	Photochemical ozone concentration	kg	photochemical oxidant formation potential	POFP	kg (NMVOC to air)
particulate matter formation	PMF	PM_{10} intake	kg	particulate matter formation potential	PMFP	kg (PM_{10} to air)
terrestrial ecotoxicity	TET	hazard-weighted concentration	$m^2 \times yr$	terrestrial ecotoxicity potential	TETP	kg (14DCB to industrial soil)
freshwater ecotoxicity	FET	hazard-weighted concentration	$m^2 \times yr$	freshwater ecotoxicity potential	FETP	kg (14DCB to freshwater)
marine ecotoxicity	MET	hazard-weighted concentration	$m^2 \times yr$	marine ecotoxicity potential	METP	kg (14-DCB to marine water)
ionizing radiation	IR	absorbed dose	man×Sv	ionizing radiation potential	IRP	kg (U^{235} to air)
agricultural land occupation	ALO	occupation	$m^2 \times yr$	agricultural land occupation potential	ALOP	$m^2 \times yr$ (agricultural land)
urban land occupation	ULO	occupation	$m^2 \times yr$	urban land occupation potential	ULOP	$m^2 \times yr$ (urban land)
natural land transformation	NLT	transformation	m^2	natural land transformation potential	NLTP	m^2 (natural land)
water depletion	WD	amount of water	m^3	water depletion potential	WDP	m^3 (water)
mineral resource depletion	MRD	grade decrease	kg^{-1}	mineral depletion potential	MDP	kg (Fe)
fossil resource depletion	FD	lower heating value	MJ	fossil depletion potential	FDP	kg (oil)

Table 14: ReCiPe impact categories

All midpoint values are expressed in units of a reference substance and related to the three (3) damage categories. This method first converts the life cycle inventory (such as amount of carbon dioxide released or heavy metals used) into midpoint impact categories (such as human toxicity and ozone depletion). These environmental impacts are then aggregated into damage categories. The three (3) ReCiPe damage categories are:[29]

1) Human Health in disability-adjusted life years lost (DALY)
2) Ecosystems damage in species years lost
3) Resources lost in marginal dollar cost

Life cycle environmental impacts are calculated using the ReCiPe (H) framework. The Hierarchical (H) version offers a balanced time perspective between long-term and short-term effects, as well as probability of occurrence and justifying evidence. This framework follows the guidelines of governmental bodies and established international organizations, lending further to its credibility.[30] This cultural point of view can be viewed as a representative balance for a seller of consumer products.

[29] The exact details of these categories, indicators and characterization factors can be found in the full ReCiPe 2012 report available at http://www.lcia-recipe.net/.

[30] Goedkoop M.J., Heijungs R, Huijbregts M., De Schryver A.;Struijs J., Van Zelm R, ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level; First edition Report I: Characterisation; 6 January 2009. http://www.lcia-recipe.net/publications

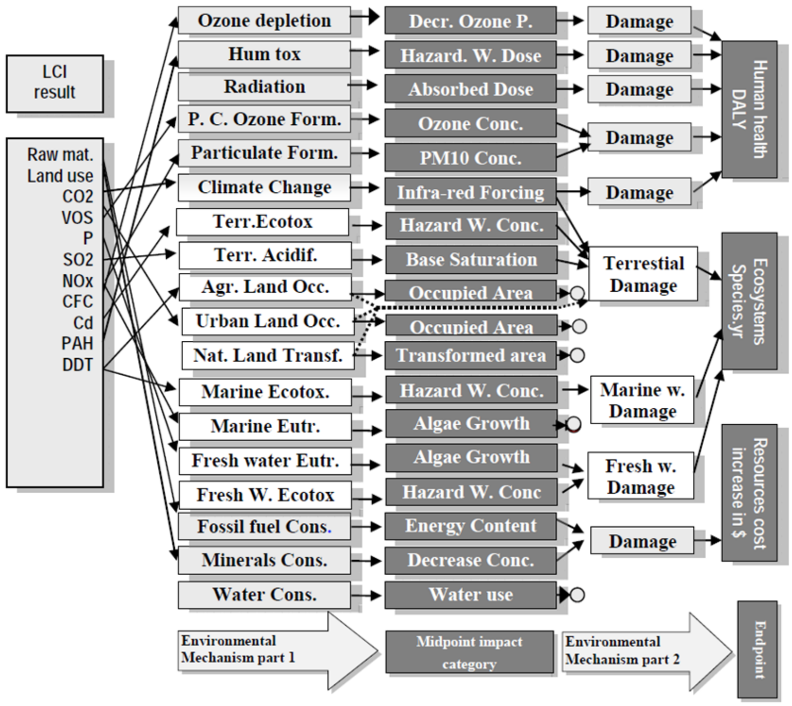

Figure 24 Data Relationship within ReCiPe

4.1.2 Cumulative Energy Demand 1.09

This analysis also used the Cumulative Energy Demand 1.09 impact assessment method, an internationally accepted method.[31] The Cumulative Energy Demand (CED) of a product represents the total direct and indirect energy use throughout the product life cycle and is widely used as a screening indicator for environmental impacts.[31] This method was chosen to provide a comparison between the energy use implications of different EOL management strategies. The purpose of many EOL management strategies is to recover or avoid energy use, and thereby extract as much value as possible from the energy already embodied within the product. CED is therefore a valuable metric by which to compare these strategies.

[31] Frischknecht R., Jungbluth N., et.al. (2010). Implementation of Life Cycle Impact Assessment Methods.ecoinvent report No.3 2010, Swiss Centre for LCI. Dübendorf, CH, www.ecoinvent.org

	subcategory	includes
non-renewable resources	fossil	hard coal, lignite, crude oil, natural gas, coal mining off-gas, peat
	nuclear	uranium
	primary forest	wood and biomass from primary forests
renewable resources	biomass	wood, food products, biomass from agriculture, e.g. straw
	wind,	wind energy
	solar	solar energy (used for heat & electricity),
	geothermal	geothermal energy (shallow: 100-300m)
	water	run-of-river hydro power, reservoir hydro power

Figure 25: Cumulative Energy Demand (CED) in Ecoinvent, category and sub category[31]

CED was chosen for this analysis to provide additional detail to specific processes and materials that may have significant embodied energy requirements. The results of CED can be used to compare the results of the Study.[31]

4.2 Ecoinvent Database

The Ecoinvent 3.1 database is used for this analysis, and the transform and market Ecoinvent activities were excluded. Ecoinvent data is maintained by the Ecoinvent Research Centre. Created in 1997, the Ecoinvent Research Centre (originally called the Swiss Centre for Life Cycle Inventories) is a Competence Centre of the Swiss Federal Institute of Technology Zürich (ETH Zurich) and Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Testing and Research (EMPA), and the Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART).[32]

The following is adapted from the Swiss Centre for Life Cycle Inventories, ecoinvent Centre, Code of Practice, Data v3.1 (2014).

> The ecoinvent data comprise life cycle inventory data covering energy (including oil, natural gas, hard coal, lignite, nuclear energy, hydro power, photovoltaics, solar heat, wind power, electricity mixes, bioenergy), transport, building materials, wood (European and tropical wood), renewable fibres, metals (including precious metals), chemicals (including detergents and petrochemical solvents), electronics, mechanical engineering (metals treatment and compressed air), paper and pulp, plastics, waste treatment and agricultural products. The entire system consists of about 4,000 interlinked datasets. Each dataset describes a life cycle inventory on a unit process level. The functional unit of all these unit

[32] Adapted from http://www.ecoinvent.org/database/introduction-to-ecoinvent-3/introduction-to-ecoinvent-version-3.html

processes is either a product or a service (whereby the product may be as large as one complete power plant manufactured for producing electricity).

Categories and subcategories are also used to describe the elementary flows. Elementary flows are identified by the flow name (e.g. “Carbon dioxide, fossil”), the category and the subcategory and the unit. Categories describe the different environmental compartments air, water, soil and resource uses. Subcategories further distinguish subcompartments within these compartments which may be relevant for the subsequent impact assessment step. The categories "air", "water" and "soil" describe the receiving compartment and are used for (direct) pollutant emissions whereas the category "resource" is used for all kinds of resource consumption. For instance, water consumption is recorded as an input in the category/subcategory "resource/in water". Land transformation and occupation is recorded as an input in the category/subcategory "resource/land."

4.3 LCIA Limitations

There are limitations inherent in the use of the damage-oriented impact assessment method. ReCiPe includes indicators that significantly impact damage categories such as human health, but no method is absolutely complete—some indicators such as heavy metals and endocrine disruptors are not calculated in ReCiPe.

In addition, as with any LCA, there are limitations on how the results should be used. LCA results should not be considered the only source of environmental information on a product or process.

Lack of primary data for OEM Avenir® production limits the comparison of the OEM model to the Davies remanufactured model. It is assumed that the data used is representative and any areas where primary data was not used a sensitivity was conducted. OEM energy use is based on 2005 data and any efficiency improvements or location changes for the OEM cannot be quantified. Primary OEM data for component mass and materials was collected directly at Davies from OEM Avenir® cores. The OEM Avenir® components assessed in this study may no longer be produced by Steelcase or the same as the current Avenir® product offering. OEM packaging is another limitation in this study, due to lack of primary data. The OEM LCA (Dietz 2005) provides data for packaging, however improvements in process and materials and quantities used cannot be determined for current OEM conditions.

5. Results

5.1 Cumulative Energy Demand (CED)

The cumulative energy demand was analyzed for both the OEM and Davies office system along with the individual component life cycles.

5.1.1 Office System Comparison (Independent life cycle method)

The complete office system is comprised of all components identified in the functional unit in Table 2. The office system comparison considers only the activities that occur at the OEM or Davies manufacturing level, indicated by the dotted circles in Figure 26, and does not include packaging, shipping, use or end-of-life of the final product. It was of most interest to evaluate and compare the manufacturing operations between the OEM and Reman. Since transportation is variable, this was evaluated separately in the sensitivity analysis. The use phase is excluded since it is assumed the OEM and Reman systems will have similar use. End of life is modeled separately for the individual components and compared across life cycles. Figure 27 illustrates the CED of an OEM office system compared to the first remanufacturing cycle (including panel indexing and material disposition) and a second remanufacturing cycle without panel indexing. The results suggest that both the reman 1 and reman 2 life cycles require 82 percent less energy than OEM production.

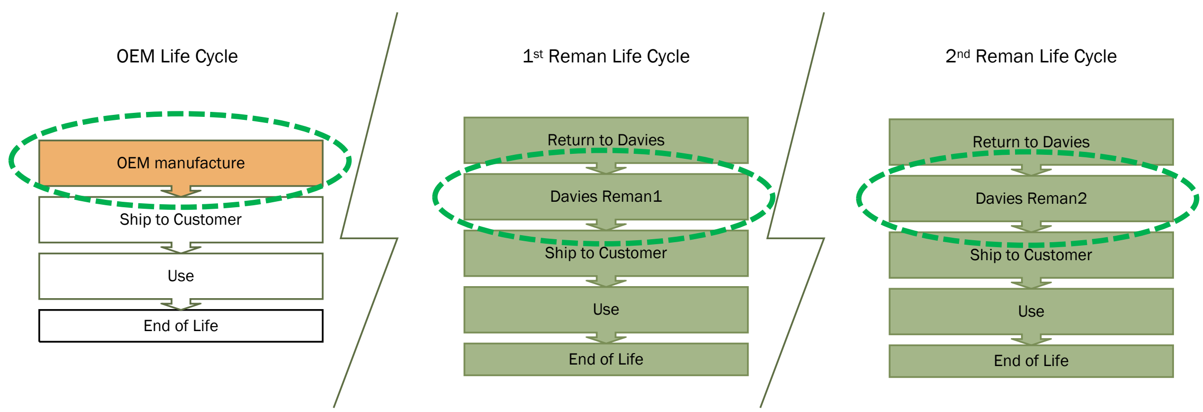

Figure 26: Office System Independent Live Cycle Comparison

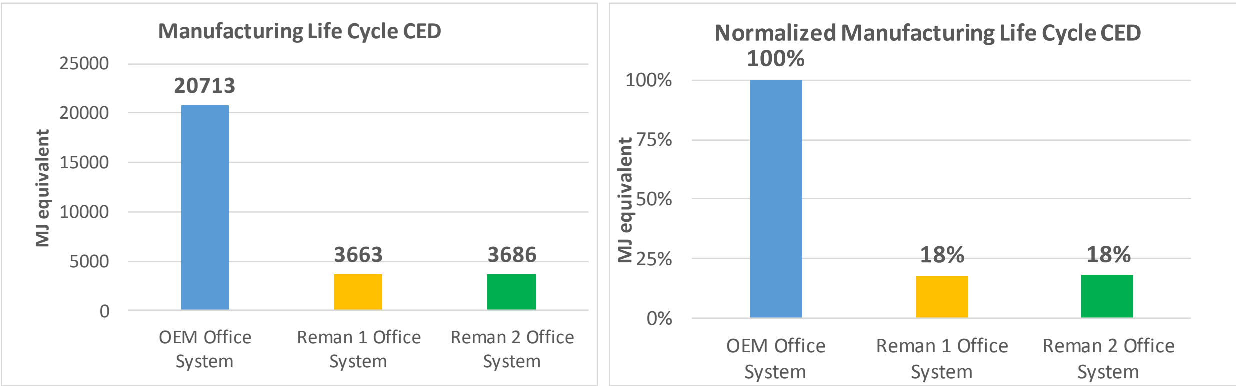

Figure 27: Office System CED Comparison

5.1.2 Divider Panel (Combined life cycle method)

Office panels defined in this study have several different sizes. One representative scenario for the 65Hx48W panel was selected for detailed analysis. This panel was seen to be a typical core height received at Davies and provides the most potential for material scrap when resizing occurs during remanufacturing. Alternatively, if the panel was not resized it would require the greatest amount of replacement materials such as fabric and fiberglass tack board. Figure 29 illustrates life cycle CED comparisons for the OEM and subsequent remanufacturing scenarios. Each life cycle starts with the OEM panel and transitions to end-of-life or subsequent remanufacturing illustrated in Figure 28. This method assumes that without first producing the OEM product, there would not be remanufacturing. The total CED for each life cycle is averaged by the number of uses within these life cycles. In the first remanufacturing life cycle, it is assumed the panel will be indexed from its original size to a smaller size in accordance with customer specifications. Results suggest that the combined OEM and first remanufacturing cycle averaged over the two life cycles is 58 percent of the OEM life cycle. The second combined remanufacturing cycle is 45 percent of the OEM. This trend indicates that there is increasing benefit as the number of remanufacturing cycles increase.

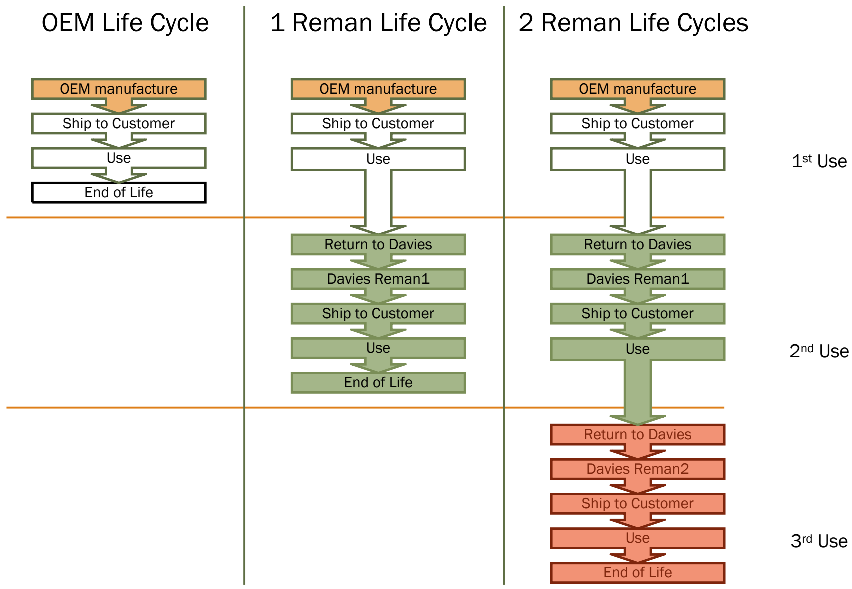

Figure 28: Combined Life Cycle Scenarios

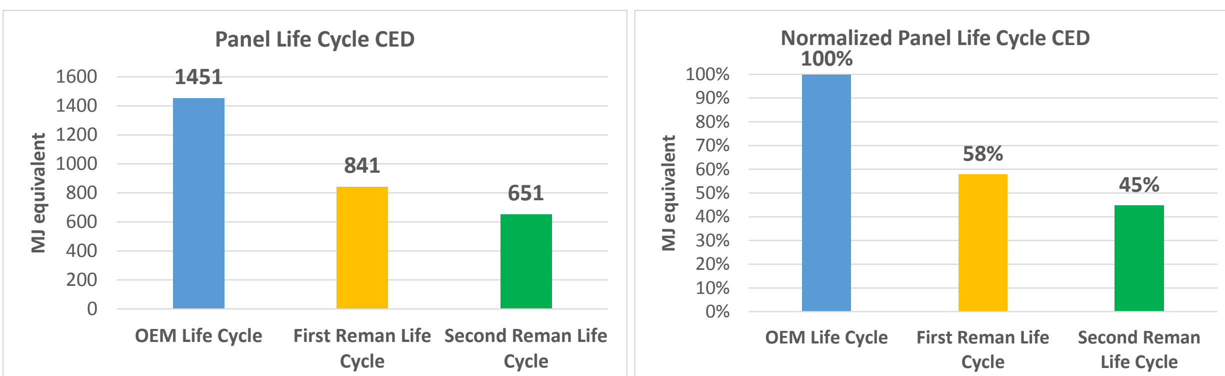

Figure 29: Divider Panel Life Cycle CED Comparison

5.1.3 Work Surface (Combined life cycle method)

An individual 48W x 24D inch work surface was discreetly analyzed and compared across combined life cycles. The combined work surface CED life cycles takes on a similar pattern as previously illustrated with the panel. The first and second remanufacturing life cycle of the work surface is 60 and 46 percent respectively of the OEM CED.

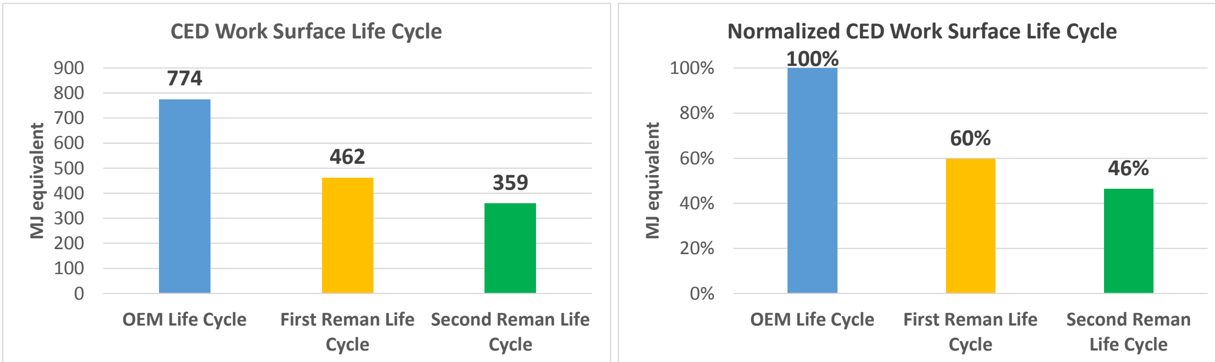

Figure 30: Work Surface Life Cycle CED Comparison

5.1.4 Lateral File (Combined life cycle method)

The combined life cycle CED of a 2 drawer lateral file is compared to one another for the three life cycles defined. The difference between the OEM and remanufactured life cycles is slightly less, where reman 1 and reman 2 are 37 percent and 50 percent less than OEM. This can be attributed to the powder coating process intensity and will be further explored in the next section.

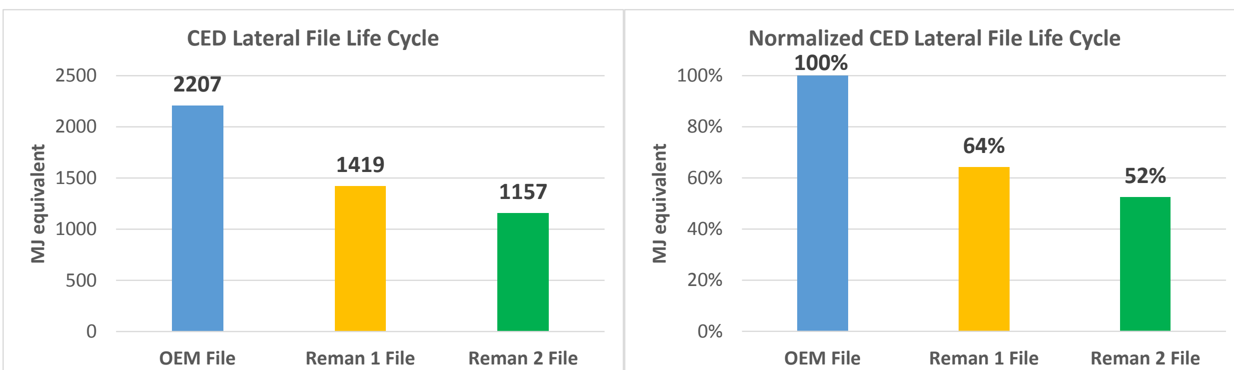

Figure 31: Lateral File Life Cycle CED Comparison

5.2 Environmental Impact

All environmental impact results for the ReCiPe method are reported in the following sections. The Climate Change Midpoint was selected for closer analysis and is described in the following section. In general, the normalized environmental impacts from each category have a similar ratio between life cycles with the exception of Ozone depletion and metal depletion.

5.2.1 Climate Change Midpoint

The “climate change” midpoint category is the anthropogenic greenhouse effect caused by the emissions of human activities. The ReCiPe impact assessment method uses a known environmental mechanism as the basis for the modelling. An environmental mechanism is a series of independent or interrelated effects that together can create damage to human health, ecosystems, or resources.

For example, a number of substances increase radiative forcing in the atmosphere, preventing heat from escaping the earth back into space. As a result, more energy is trapped on earth, and temperature increases. The outcome is that we can expect changes in habitats, and therefore some species may go extinct. This progression is shown in Figure 32, which is figure 3.1 from the ReCiPe assessment document.[33]

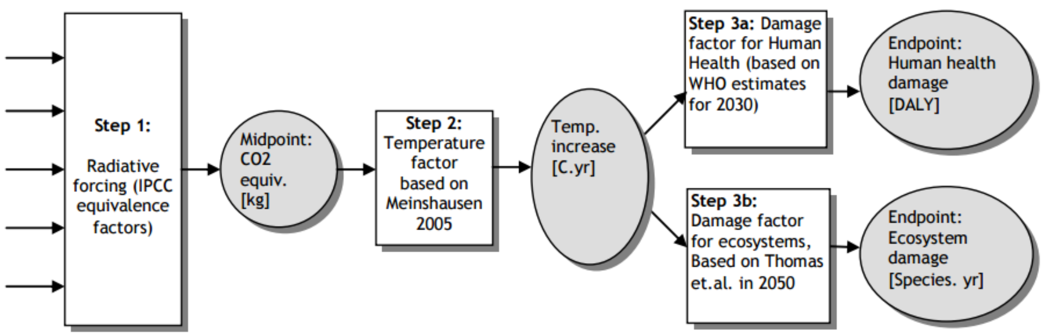

Figure 3.1: Overview of the steps in modelling effects of greenhouse gases with respect to climate change.

Figure 32: ReCiPe Modeling of Climate Change

This model therefore reports the lower uncertainty climate change midpoint values in kg of CO_2 equivalents based on factors developed by the UN’s Intergovernmental Panel on Climate Change (IPCC 2007). Factors are expressed over a standard 100-year time horizon.

5.2.2 Office System Comparison (Independent life cycle method)

Similar to CED, the environmental impact for the manufacturing cycles follow the same trend. Figure 33 shows the climate change impact for each system, where the normalized reman 1 and reman 2 system are both 83 percent less than the OEM. The first reman life cycle is slightly more impactful compared to

[33] Goedkoop, M., ReCiPe 2008, A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level, First edition, Report I: Characterisation, PRé Consultants, http://www.leidenuniv.nl/cml/ssp/publications/recipe_characterisation.pdf

the second reman cycle. This can be attributed to the indexing of the divider panels in the reman 1 life cycle.

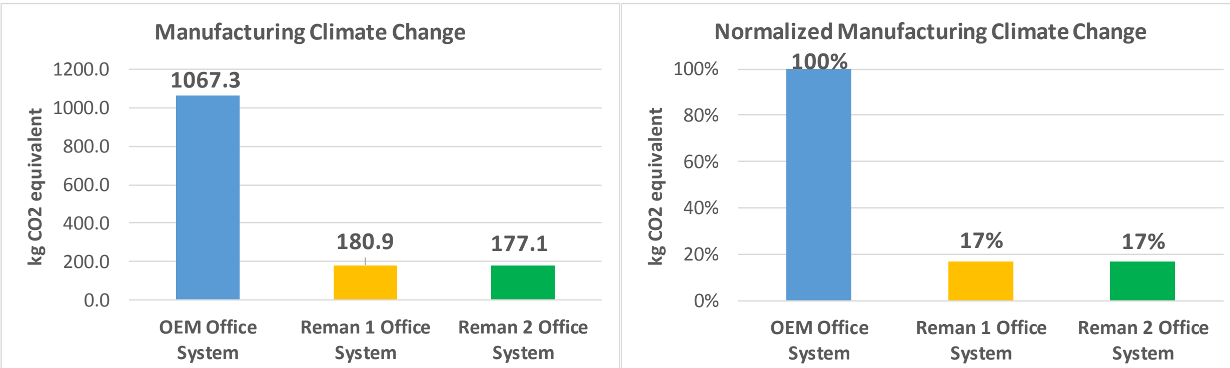

Figure 33: Office System Climate Change Comparison

Table 15 and Figure 34 displays the values for all of the impact categories for all three office systems. Significant differences between the OEM and remanufactured systems can be attributed to several areas. The OEM system steel material and processing is a significant contributor to the impacts which is illustrated Figure 39. While Davies only performs minor cutting and welding operations on some panels. The OEM and Reman scenarios were all generated using the ReCiPe 2014 method. Raw data from the OEM study was utilized in the current method to create the OEM model.

Impact category	**Unit**	**OEM Office System**	**Reman 1 Office System**	**Reman 2 Office System**
Climate change	kg CO2 eq	1067.3	180.9	177.1
Ozone depletion	kg CFC-11 eq	2.87E-04	2.18E-04	2.23E-04
Terrestrial acidification	kg SO2 eq	4.0	0.6	0.6
Freshwater eutrophication	kg P eq	5.62E-01	7.12E-02	7.05E-02
Marine eutrophication	kg N eq	2.83E-01	3.33E-02	3.04E-02
Human toxicity	kg 1,4-DB eq	602.0	62.6	62.1
Photochemical oxidant formation	kg NMVOC	3.0	0.4	0.4
Particulate matter formation	kg PM10 eq	2.3	0.2	0.2
Terrestrial ecotoxicity	kg 1,4-DB eq	1.94E-01	1.28E-02	1.26E-02
Freshwater ecotoxicity	kg 1,4-DB eq	22.4	1.4	1.4
Marine ecotoxicity	kg 1,4-DB eq	22.1	1.4	1.4
Ionising radiation	kBq U235 eq	282.6	50.9	50.4
Agricultural land occupation	m2a	91.4	16.2	17.4
Urban land occupation	m2a	11.9	0.8	0.8

Impact category	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
Natural land transformation	m2	2.05E-01	2.90E-02	2.88E-02
Water depletion	m3	17.7	1.0	1.0
Metal depletion	kg Fe eq	749.9	5.6	5.3
Fossil depletion	kg oil eq	334.1	63.3	62.8

Table 15: ReCiPe Midpoint Office System Impact

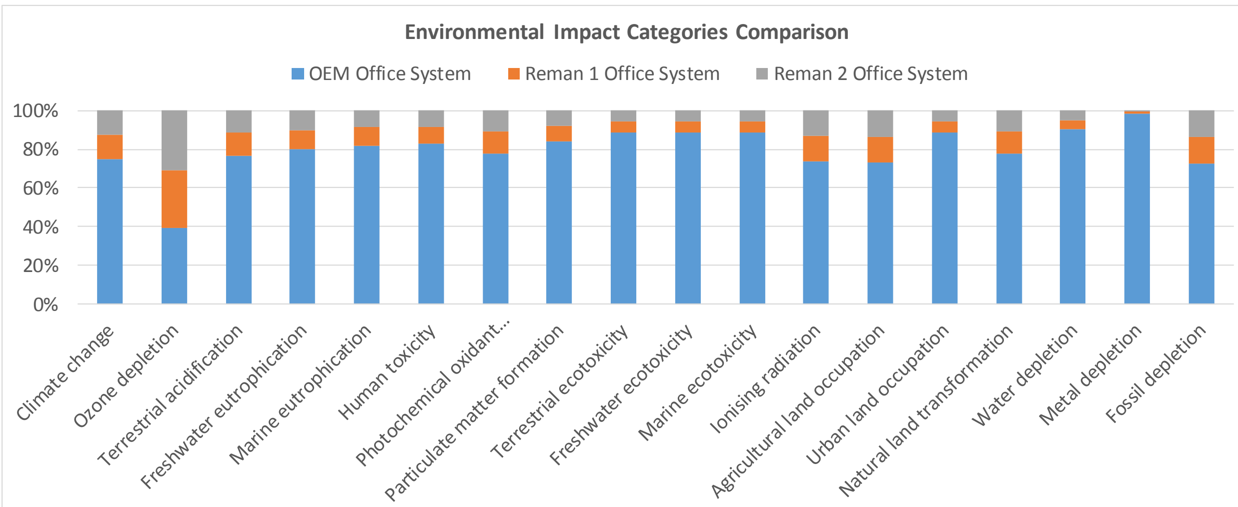

Figure 34: Office System Impact Comparison from ReCiPe Midpoint

The impacts for Ozone Depletion have less improvement compared to the other categories from OEM to reman. As illustrated in Figure 35 the first and second reman life cycles are only 76% and 78% respectively of the OEM.

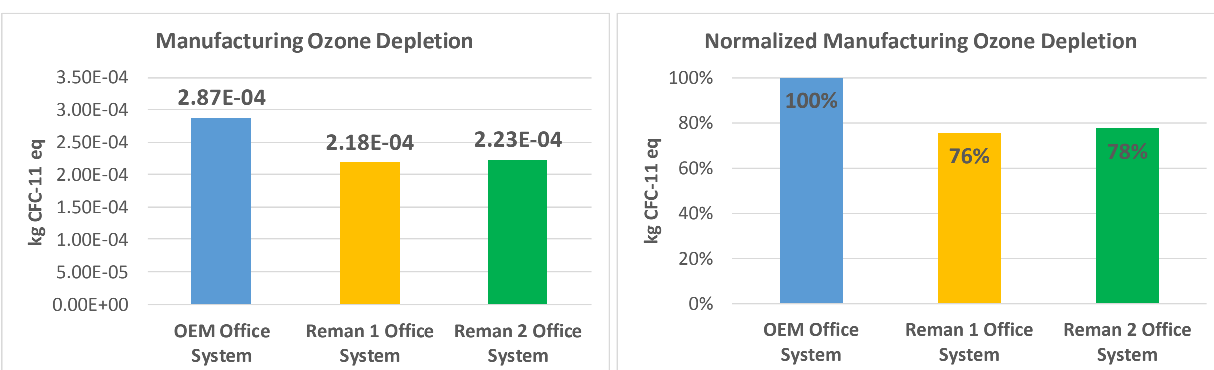

Figure 35: Office System Life Cycle Ozone Depletion

5.2.3 Divider Panel (Combined life cycle method)

The environmental impacts of a single panel life cycles in Figure 36 follow the same pattern as in the previously discussed CED comparison for the combined life cycle method.

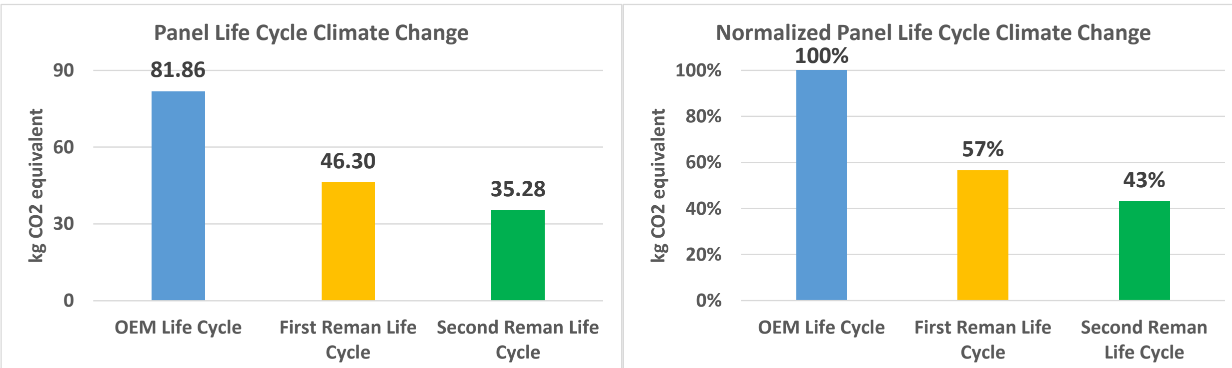

Figure 36: Panel Life Cycle Climate Change Comparison

Table 16 and Figure 37 displays all eighteen impact category results for the panel. Each category follows the same trend as the climate change, discussed previously, with varying degrees of magnitude.

Impact category	**Unit**	***OEM Life Cycle***	**First Reman Life Cycle**	**Second Reman Life Cycle**
Climate change	kg CO2 eq	81.86	46.30	35.28
Ozone depletion	kg CFC-11 eq	4.06E-05	3.32E-05	3.14E-05
Terrestrial acidification	kg SO2 eq	0.32	0.18	0.14
Freshwater eutrophication	kg P eq	0.04	0.02	0.02
Marine eutrophication	kg N eq	0.03	0.02	0.01
Human toxicity	kg 1,4-DB eq	37.34	20.31	15.28
Photochemical oxidant formation	kg NMVOC	0.21	0.12	0.09
Particulate matter formation	kg PM10 eq	0.12	0.07	0.05
Terrestrial ecotoxicity	kg 1,4-DB eq	0.02	0.01	0.01

Impact category	Unit	*OEM Life Cycle*	First Reman Life Cycle	Second Reman Life Cycle
Freshwater ecotoxicity	kg 1,4-DB eq	1.25	0.64	0.47
Marine ecotoxicity	kg 1,4-DB eq	1.20	0.62	0.45
Ionising radiation	kBq U235 eq	24.31	14.20	10.92
Agricultural land occupation	m2a	4.39	2.26	1.56
Urban land occupation	m2a	0.81	0.41	0.29
Natural land transformation	m2	0.02	0.01	0.01
Water depletion	m3	2.05	1.05	0.72
Metal depletion	kg Fe eq	15.40	5.66	3.88
Fossil depletion	kg oil eq	24.86	14.33	11.08

Table 16: ReCiPe Midpoint Panel Impact

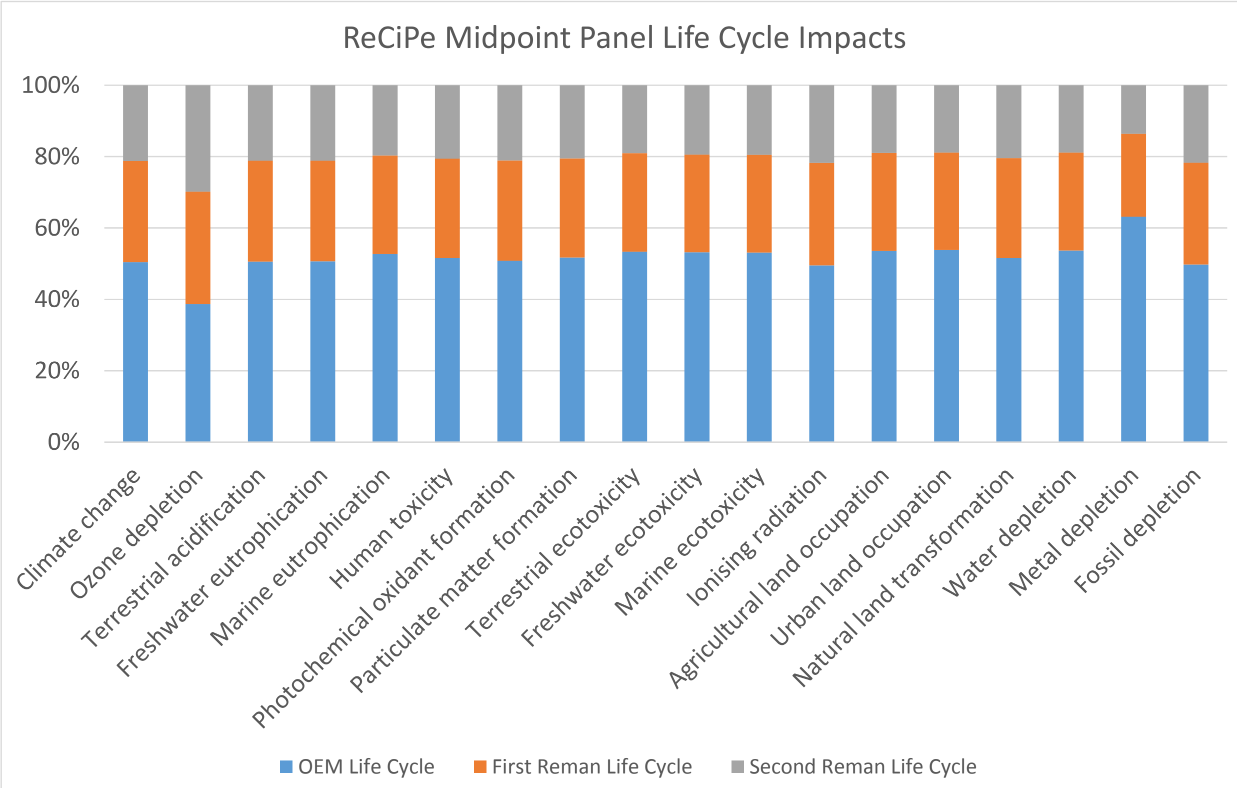

Figure 37: ReCiPe Midpoint Panel Life Cycle Impacts

Figure 39 shows a comparison of the grouped categories within the life cycles. Materials have the greatest impact for both OEM and Remanufacturing.

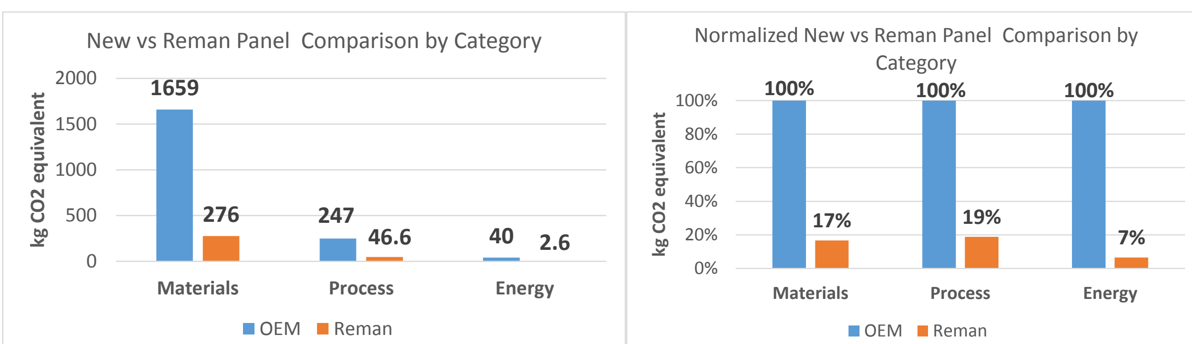

Figure 38: New vs Reman Impact Contributions to Climate Change for Panels

The majority of the OEM panel material impact is from the production of the steel components used in the panel, followed by the powder coating process.

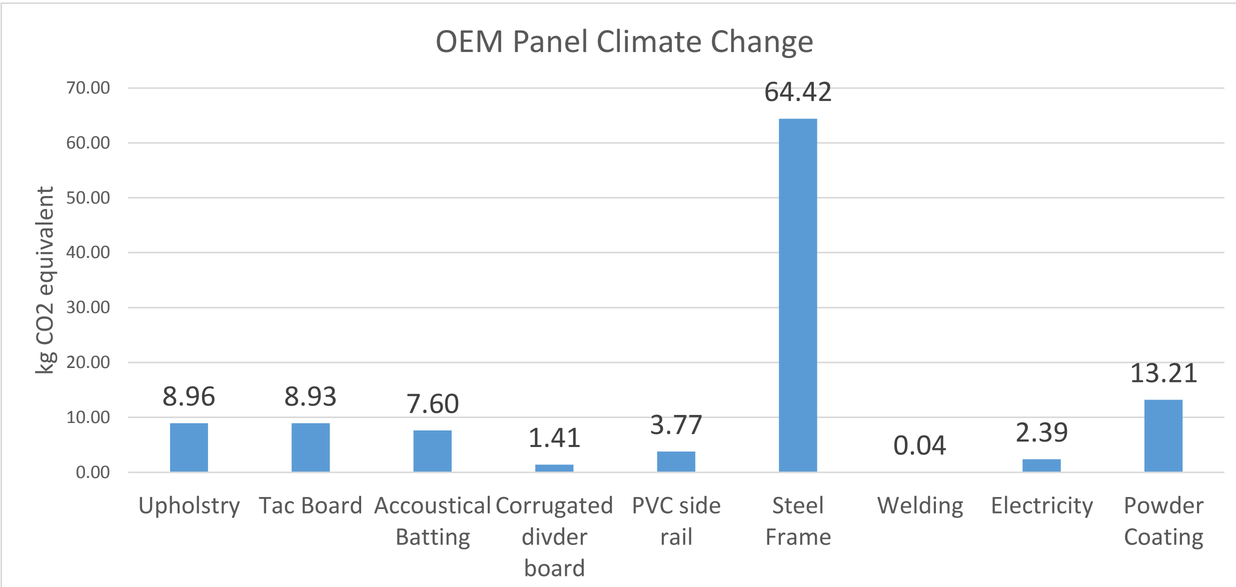

Figure 39: OEM Panel Climate Material and Process Contributors

The remanufactured panel indicates the major contributors to climate change are derived from the resources and energy used to produce the upholstery and PVC side rails illustrated in Figure 41. The next major contributor is from powder coating of the panel trim plates. The remanufacturing process receives a credit when there is indexing involved. The steel material is recycled and provides a net benefit even when combined with the transportation and disposal of the other materials removed. Figure 40 shows the network diagram at 2 percent cutoff for the discarded material from indexing.

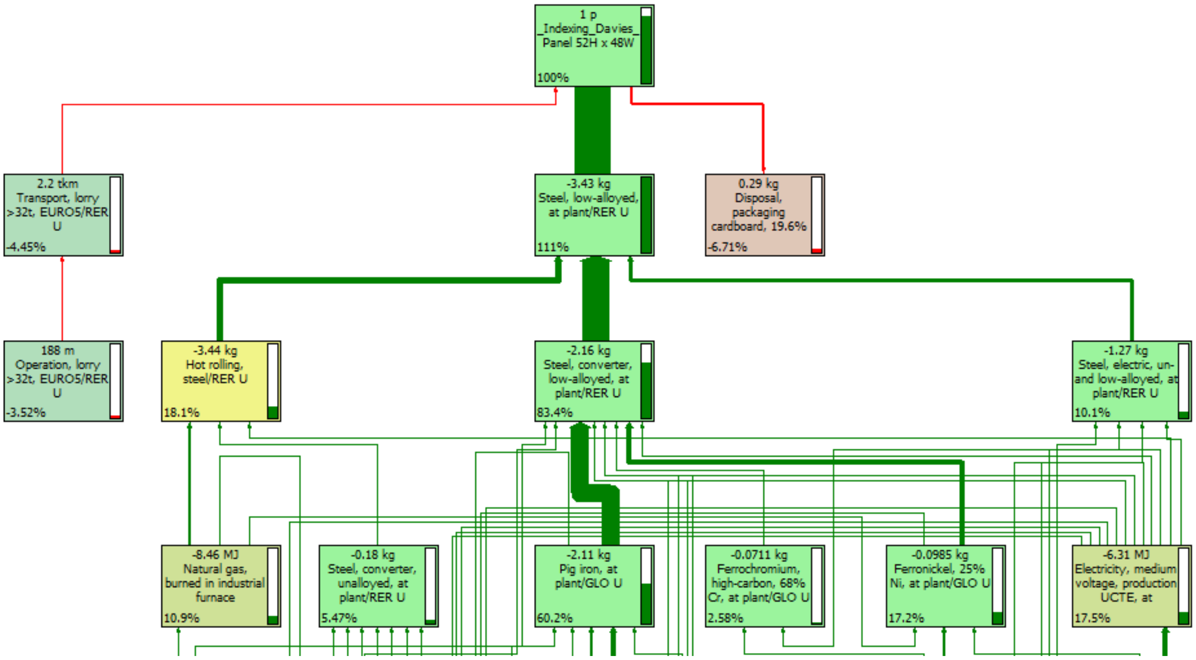

Figure 40: EOL for Indexed Materials from Panel

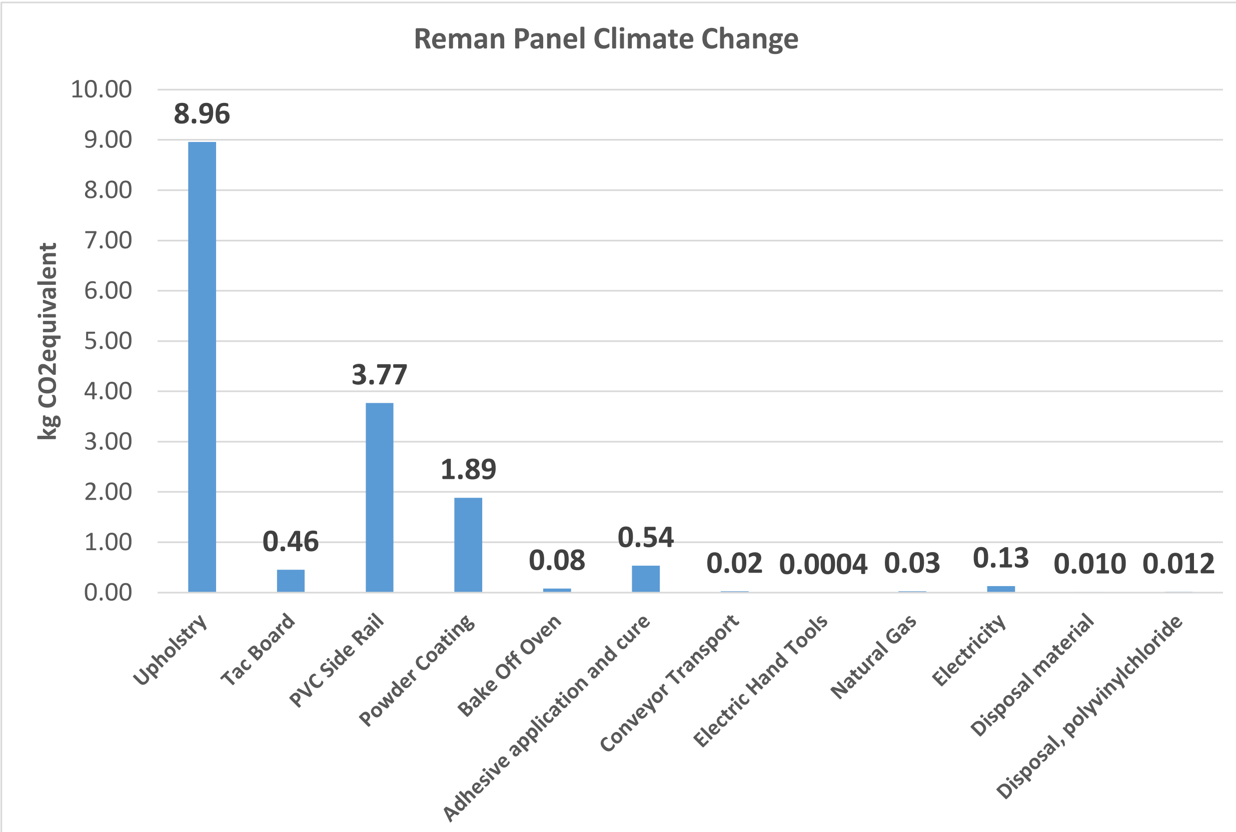

Figure 41: Davies Reman Panel Climate Material and Process Contributors

- The Polyester panel covering upholstery and PVC side rails contribute approximately 75% to 85% of the total impacts in each of the categories, illustrated in Figure 42.

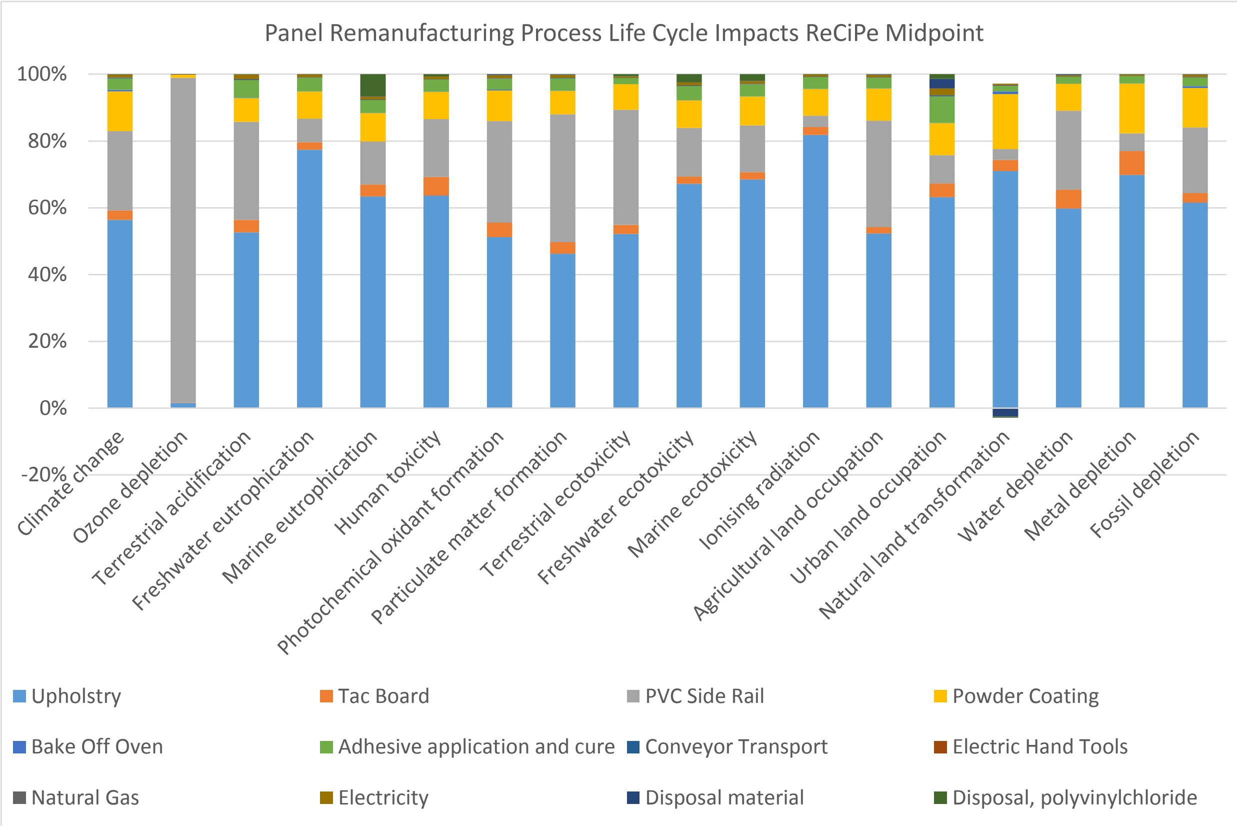

Figure 42: Remanufactured Panel Life Cycle Impacts

5.2.4 Work Surface (Combined life cycle method)

The combined life cycle method for the work surface shows that reman 1 and reman 2 are 62 and 49 percent of the OEM, respectively.

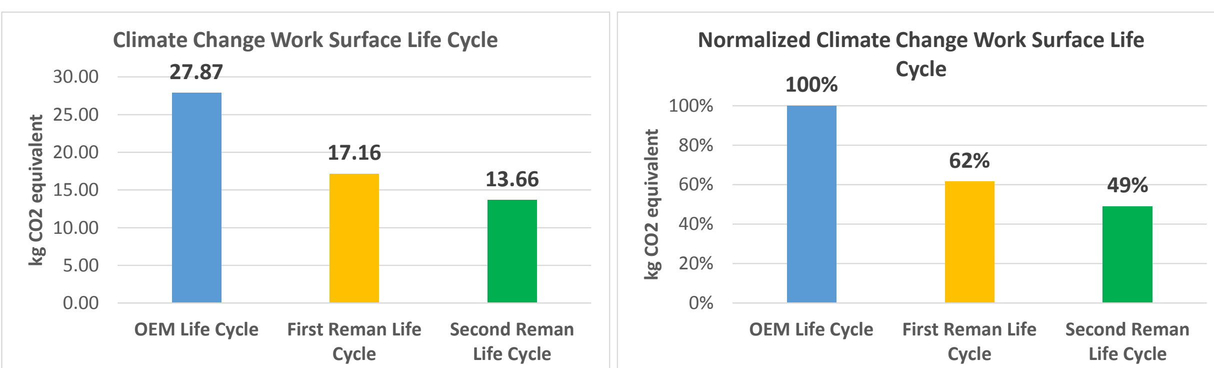

Figure 43: Work Surface Life Cycle Climate Change Comparison

Impact category	Unit	OEM Life Cycle	First Reman Life Cycle	Second Reman Life Cycle
Climate change	kg CO2 eq	27.87	17.16	13.66
Ozone depletion	kg CFC-11 eq	4.69E-06	3.77E-06	3.67E-06
Terrestrial acidification	kg SO2 eq	0.08	0.05	0.04
Freshwater eutrophication	kg P eq	0.01	0.00	0.00
Marine eutrophication	kg N eq	0.07	0.04	0.03
Human toxicity	kg 1,4-DB eq	15.65	9.14	7.00
Photochemical oxidant formation	kg NMVOC	0.07	0.05	0.04
Particulate matter formation	kg PM10 eq	0.03	0.02	0.02
Terrestrial ecotoxicity	kg 1,4-DB eq	1.55E-03	1.00E-03	8.24E-04
Freshwater ecotoxicity	kg 1,4-DB eq	3.91	2.06	1.45
Marine ecotoxicity	kg 1,4-DB eq	3.38	1.79	1.26
Ionising radiation	kBq U235 eq	3.77	2.71	2.38
Agricultural land occupation	m2a	12.45	7.82	6.28
Urban land occupation	m2a	0.33	0.21	0.16
Natural land transformation	m2	3.91E-03	2.60E-03	2.16E-03
Water depletion	m3	0.09	0.07	0.06
Metal depletion	kg Fe eq	0.80	0.53	0.45
Fossil depletion	kg oil eq	6.69	4.54	3.85

Table 17: ReCiPe Midpoint Work Surface Life Cycle Impact

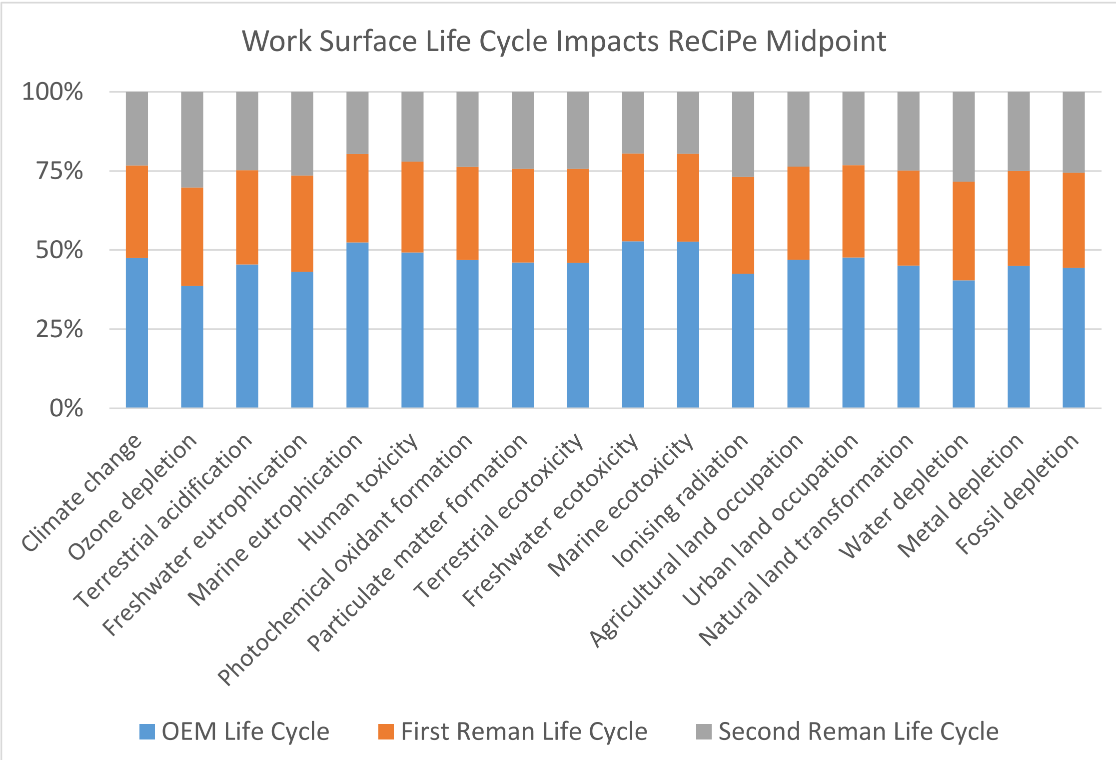

Figure 44: Work Surface Life Cycle Impacts

The greatest contributor to the OEM work surface is the particle board and laminate, followed by the manufacturing energy.

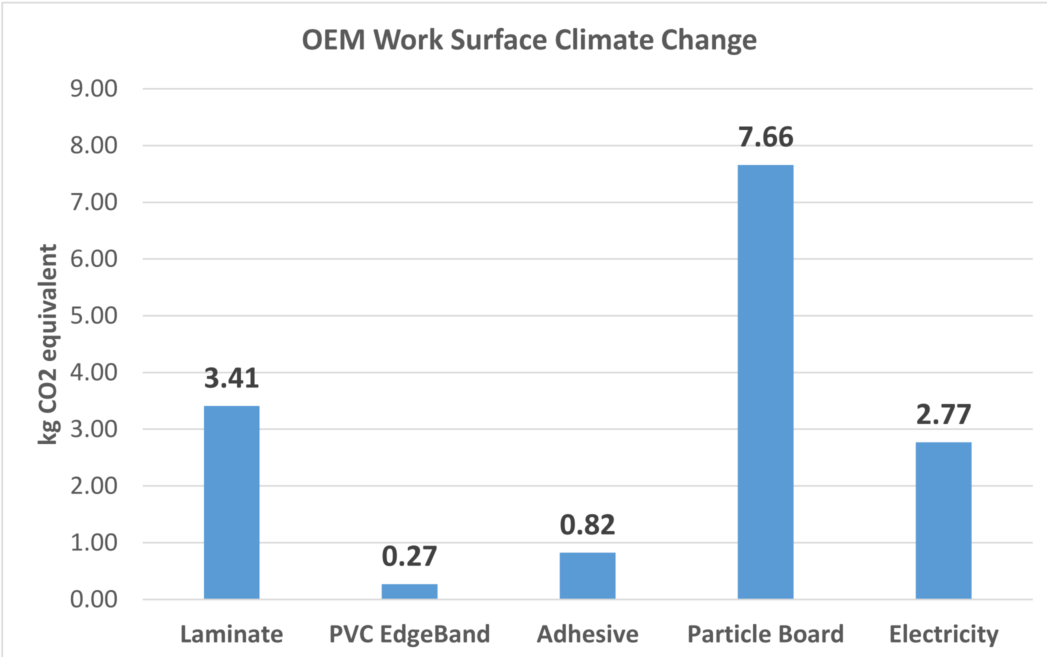

Figure 45: OEM Work Surface Climate Change Impacts

The greatest impact to the remanufacturing of the work surface is from the use of new laminate material.

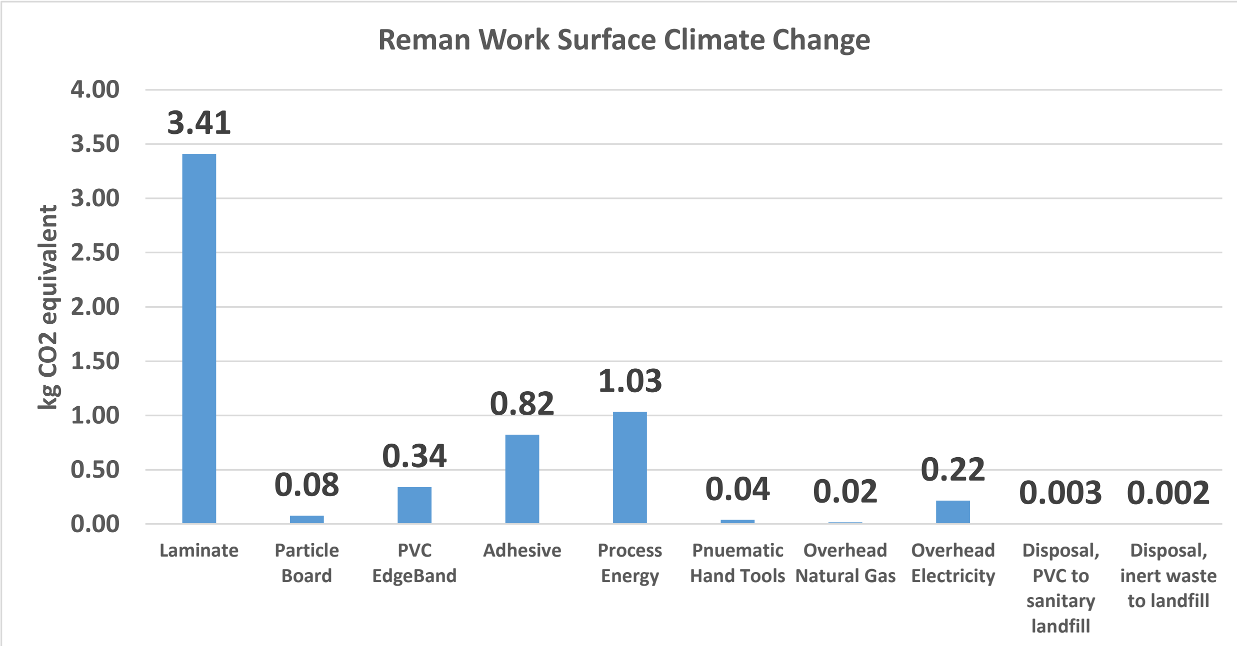

Figure 46: Reman Work Surface Climate Change Impacts

- The laminate material used on the work surface has the greatest contribution to environmental impact in a majority of the impact categories, followed by process energy, illustrated in **Figure 47**. Use of PVC edge banding contributes to over 80% of the Ozone Depletion impact.

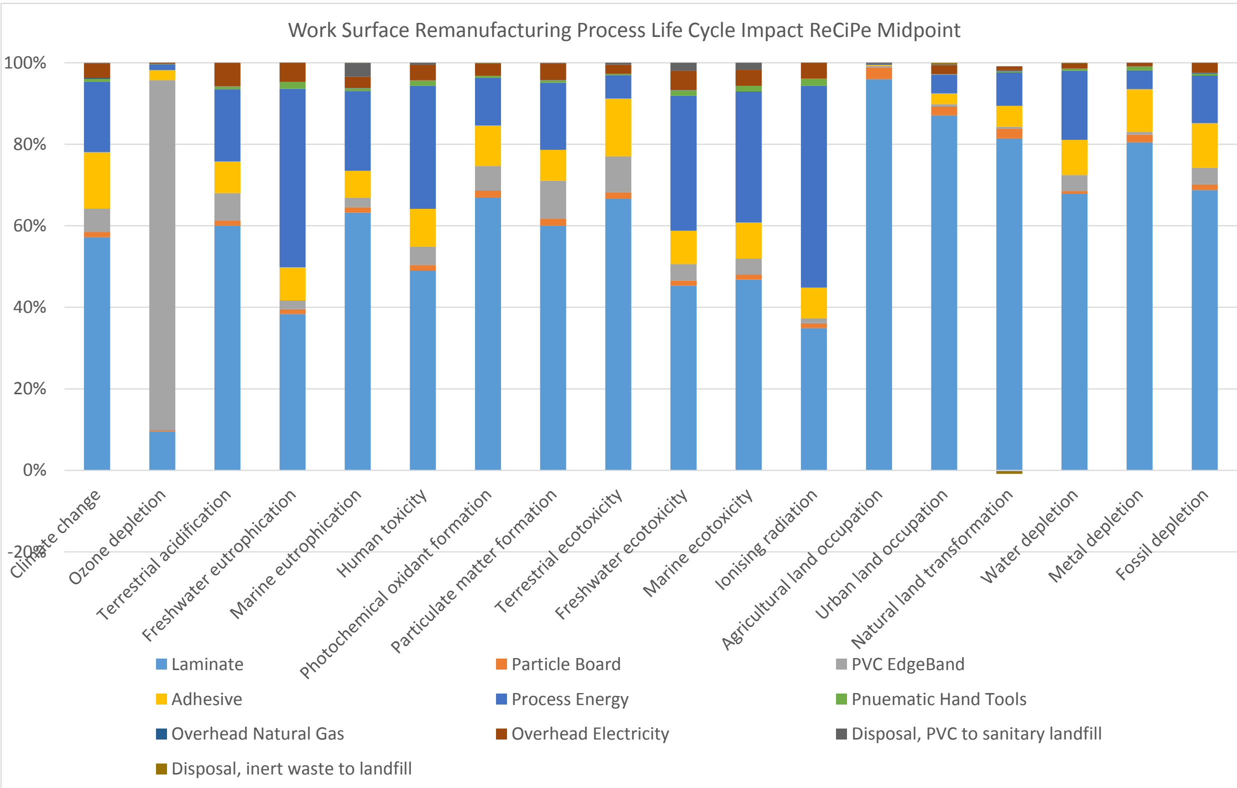

Figure 47: Remanufactured Work Surface Environmental Impacts

5.2.5 Lateral File (Combined life cycle method)

The lateral file has the least amount of impact reduction as compared to the panel and work surface for each of the remanufacturing life cycles, compared to the OEM. Reman 1 & 2 are 64 and 51 percent of the OEM.

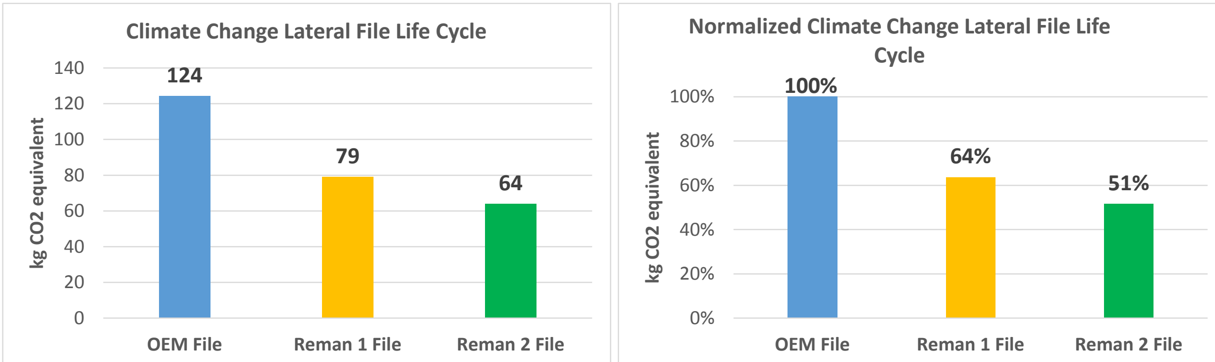

Figure 48: Lateral File Life Cycle Climate Change Comparison

Impact category	Unit	OEM File	Reman 1 File	Reman 2 File
Climate change	kg CO2 eq	124	79	64
Ozone depletion	kg CFC-11 eq	1.29E-05	9.31E-06	8.12E-06
Terrestrial acidification	kg SO2 eq	0.40	0.24	0.19
Freshwater eutrophication	kg P eq	0.07	0.04	0.03
Marine eutrophication	kg N eq	0.04	0.02	0.01
Human toxicity	kg 1,4-DB eq	57.93	33.62	25.51
Photochemical oxidant formation	kg NMVOC	0.28	0.17	0.14
Particulate matter formation	kg PM10 eq	0.18	0.10	0.08
Terrestrial ecotoxicity	kg 1,4-DB eq	0.01	0.01	0.00
Freshwater ecotoxicity	kg 1,4-DB eq	2.56	1.39	1.00
Marine ecotoxicity	kg 1,4-DB eq	2.46	1.34	0.97
Ionising radiation	kBq U235 eq	41.57	24.60	18.94
Agricultural land occupation	m2a	2.31	1.34	1.01
Urban land occupation	m2a	1.66	0.87	0.61
Natural land transformation	m2	0.03	0.02	0.01
Water depletion	m3	1.41	0.77	0.56
Metal depletion	kg Fe eq	37.68	19.37	13.26
Fossil depletion	kg oil eq	37.37	24.52	20.23

Table 18: ReCiPe Midpoint Lateral File Life Cycle Impact

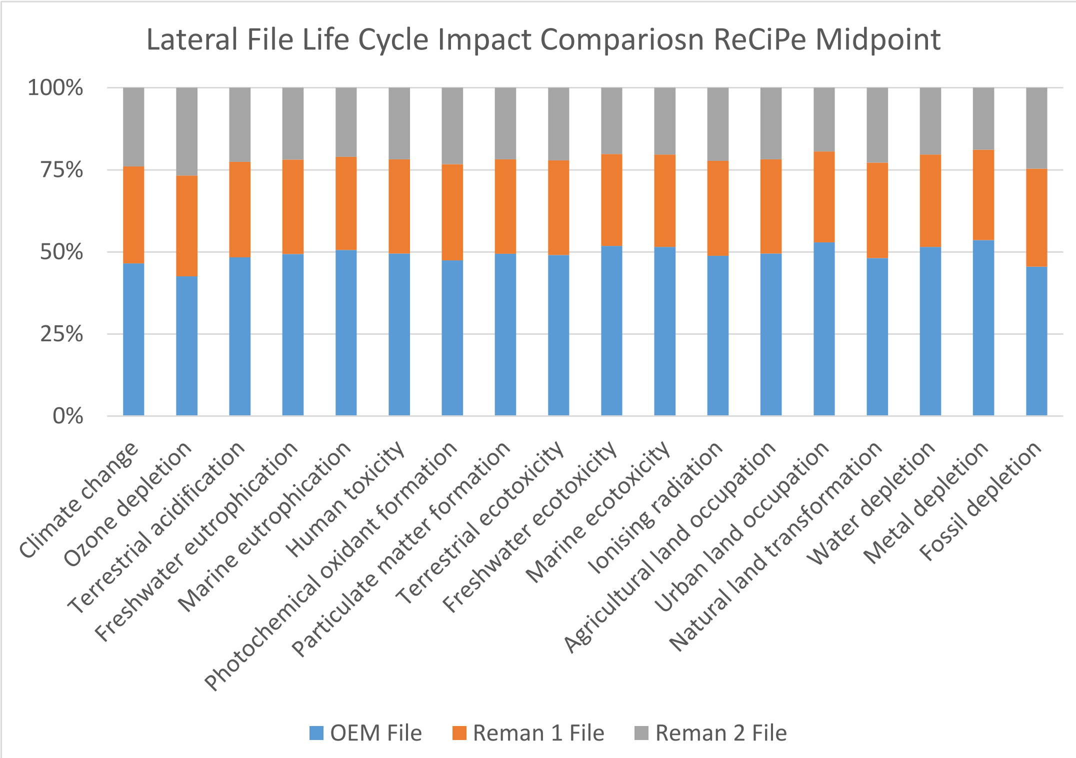

Figure 49: ReCiPe Midpoint Lateral File Life Cycle Impact

As with the panel, the steel material manufacturing is the main contributor to the environmental impacts followed by powder coating.

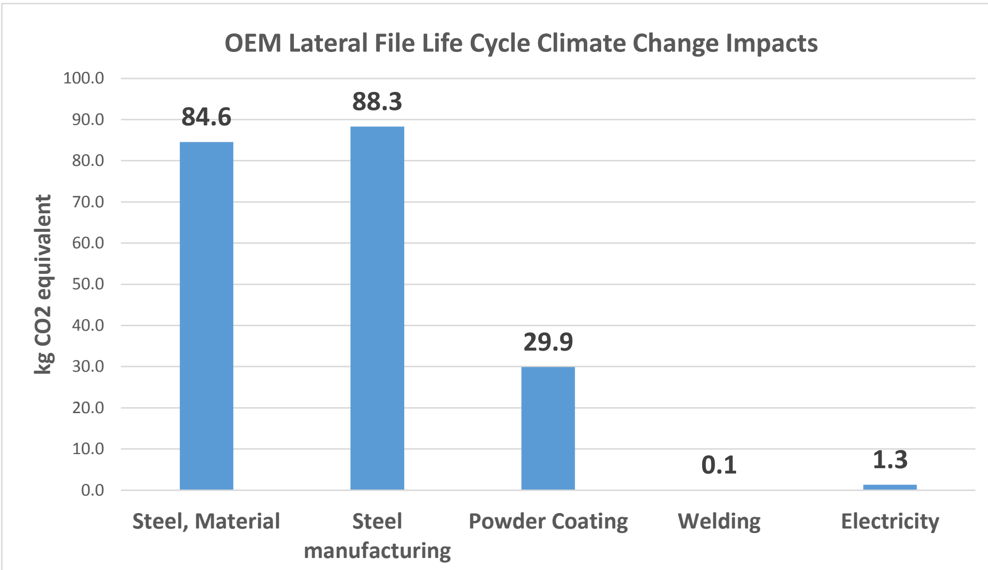

Figure 50: OEM Lateral File Climate Change Impacts

The greatest impact to remanufacturing is from the powder coating of the files. The other processes use minimal energy and materials.

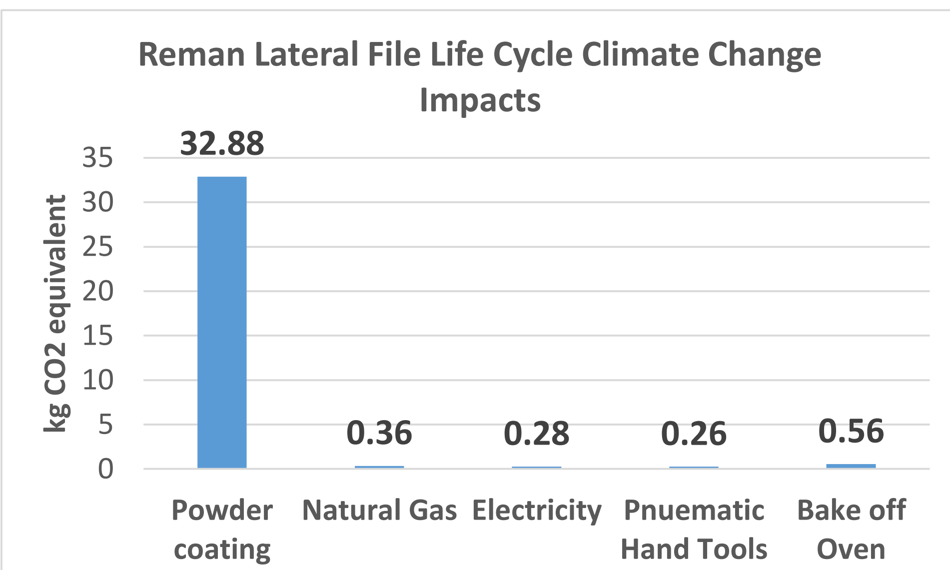

Figure 51: Reman Lateral File Climate Change Impacts

- Powder Coating is identified as a significant contributor to the life cycle impacts for the remanufactured file and pedestal illustrated in Figure 52. The inventory data identifies the presence of Chrysotile (asbestos) which can be traced back to the powder coat process.

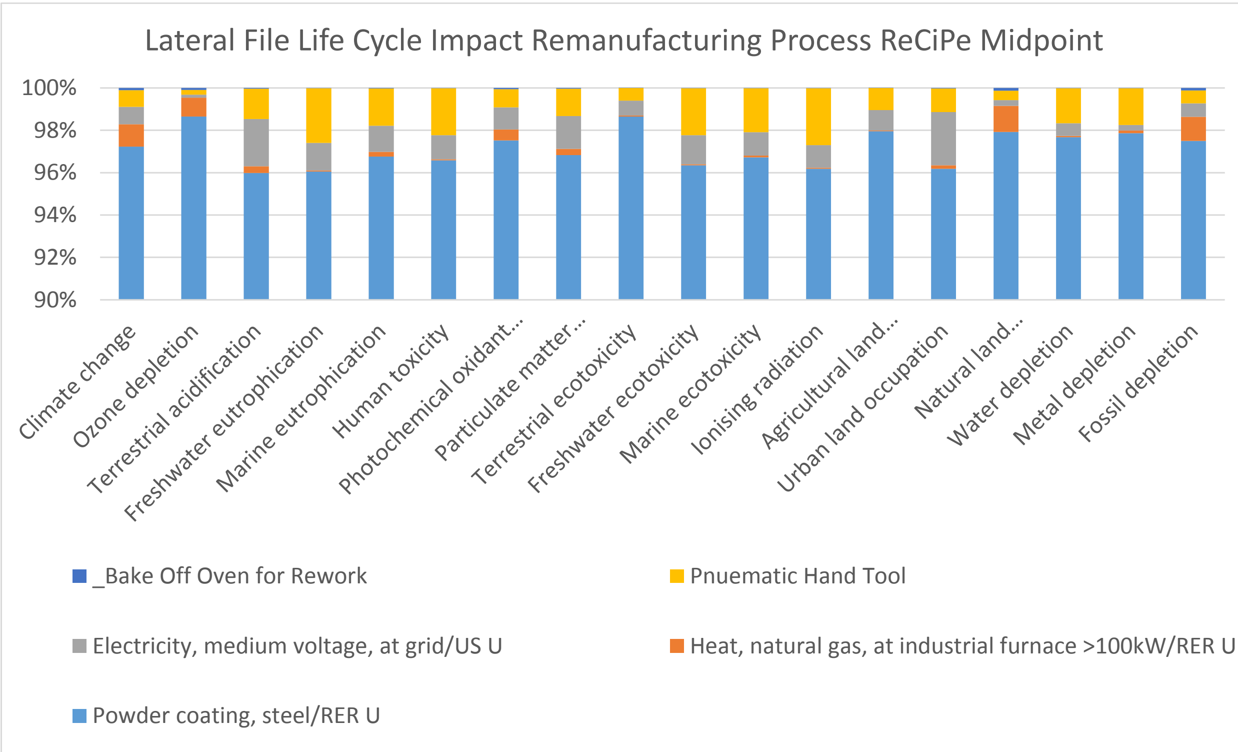

Figure 52: Remanufactured File Environmental Impacts

5.3 Sensitivity Analysis

A sensitivity analysis was performed for the Davies remanufactured office system for several parameters. The parameters chosen were transportation distance, replacement rates of materials for the components analyzed, packaging materials and production impacts due to energy production fuel mix. Davies provided typical replacement rates for components based on how often a part may not be reused due to damage or other defects. Higher replacement rates will likely result in worse environmental impact. There are many scenarios that could be explored in the sensitivity analysis, but this analysis focused on those situations that could reasonably occur.

Transportation was chosen due to the fact that Davies has to ship the office system core back to their location for remanufacture and then back to the client. This would suggest that remanufactured transportation distances would be greater than OEM distances. Secondly weights of the office systems will vary between the OEM and Reman. Panels that are indexed will have a reduced weight, while additional laminate added to the work surface over the old laminate will add weight to the system. Distance traveled for the reman product was varied to determine how the impacts are influenced by this measure. The results of this may also be of interest to Davies in determining other methods of remanufacture that might reduce the impacts of transportation and where this would be most beneficial.

Replacement rates of materials during Davies process are assumed accurate, however it was of interest to understand the potential impact when material replacement rates increased. It was of particular interest to evaluate the effects of increased material use during subsequent life cycles. Davies does not currently have a standardized method for tracking how many times a product has been through the remanufacturing process, therefore change in replacement rates may differ from the first to the second reman cycle.

Energy production by fuel type varies by location, where some areas favor more energy from renewable sources such as wind, solar and hydroelectric. While other areas favor production from fossil fuels such as coal and petroleum products. Variation in energy production by fuel type may have a discernable impact on the environmental results. The main study assumed both OEM and Davies used the average US energy mix. This was done to eliminate location biased analysis regarding energy and eliminate that variability to identify other potential contributors within the manufacturing process. The original OEM LCA assumed an energy mix in Michigan, which was conducted in 2005 (Dietz 2005). It can be assumed that current OEM manufacturing occurs in Mexico, while Davies remanufacturing occurs in New York State. The energy mix sensitivity will evaluate the variation from the US average to that of the OEM compared to Davies. The fuel type by location and allocation can be seen in Table 19. The New York mix is predominately natural gas, nuclear and hydroelectric, with less than 2% coal and petroleum combined. Mexico has a comparable natural gas contribution but has a larger contribution from petroleum and coal primarily due to the lack of nuclear production. The US average has a significant contribution from coal and petroleum which could cause a shift in the impact results.

Category	New York [34]	Mexico[35]	Michigan[36]	US Avg[37]
Petroleum-Fired	0.13%	16.40%	0.12%	5.66%
Natural Gas-Fired	47.24%	50.40%	27.24%	17.30%
Coal-Fired	1.30%	12.90%	37.56%	47%
Nuclear	27.19%	3.90%	28.80%	19.60%
Hydroelectric	19.75%	13.80%	1.34%	8.15%
Other Renewables	4.38%	2.54%	4.94%	1.49%

Table 19: Energy Mix by Fuel Type and Location

The main component in the work surface that was varied to test sensitivity was the replacement rate of the particle board. The original scenario as reported by Davies for replacement rates indicates that one out of every one hundred (1/100) work surfaces is not suitable for remanufacture and requires new particle board. The sensitivity scenario evaluated what the impact of increased replacement rates would be for the remanufactured work surface. Material, process energy, and disposal of the old materials are all included.

Work Surface	Original		Sensitivity 1	
Component Description	**Reuse Yield 1st Reuse**	**Reuse Yield 2nd Reuse**	**Reuse Yield 1st Reuse**	**Reuse Yield 2nd Reuse**
Work Surface Core	99%	99%	95%	86%
Laminate	0%	0%	0%	0%
PVC Edge band	0%	0%	0%	0%

Table 20: Work surface Sensitivity Variation

Results of the sensitivity analysis for the work surface, Figure 53, show a minimal increase in climate change impact for increased replacement of particle board. The total increase for both life cycles is 1.44 kg CO2 equivalent.

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34 US Energy Information Administration, New York Net Electricity Generation by Source Jun. 2016 http://www.eia.gov/state/?sid=NY#tabs-4

35 Center for Energy Economics Bureau of Economic Geology, The University of Texas and Austin and Instituto Tecnologico y de Estudios Superiores de Monterrey, Guide to Electric Power in Mexico, 2013 Second Edition

36 US Energy Information Administration, Michigan Net Electricity Generation by Source Jun. 2016 http://www.eia.gov/state/?sid=MI#tabs-4

37 Ecoinvent 3 Database

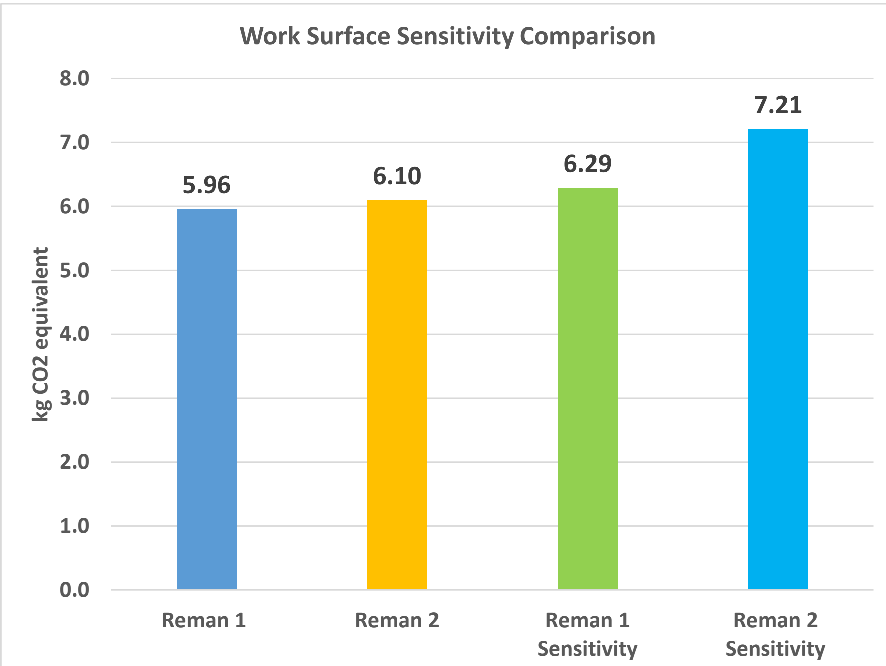

Figure 53: Work Surface Sensitivity Comparison for Climate Change

The sensitivity analysis for the panel, evaluated one panel that would not be indexed, focused on the potential variation of material inputs. As with the work surface, Davies provided the typical replacements for the panel materials. In the original scenario, only tack board is replaced at a rate of one out of every twenty (1/20) for both reman 1 and reman 2. The sensitivity scenario assumed a greater replacement rate for reman 1 and reman 2. Also considered was the replacement of the acoustical filler and chipboard divider as shown in Table 21.

Panel	Original		Sensitivity 1	
Component Description	**Reuse Yield 1st Reuse**	**Reuse Yield 2nd Reuse**	**Reuse Yield 1st Reuse**	**Reuse Yield 2nd Reuse**
Panel Frame with legs	100%	100%	100%	100%
Top Cap	100%	100%	100%	100%
side rails	0%	0%	0%	0%
snap on frame	100%	100%	100%	100%
Fabric Skin	0%	0%	0%	0%
Tack Board	95%	95%	90%	85%
Acoustical Filler	100%	100%	99%	97%
Chipboard Divider	100%	100%	99%	97%

Table 21: Panel Sensitivity Variation

Sensitivity results for the panel, Figure 54, show that the climate change impact would only increase by a total of 1.72 kg CO2 equivalent.

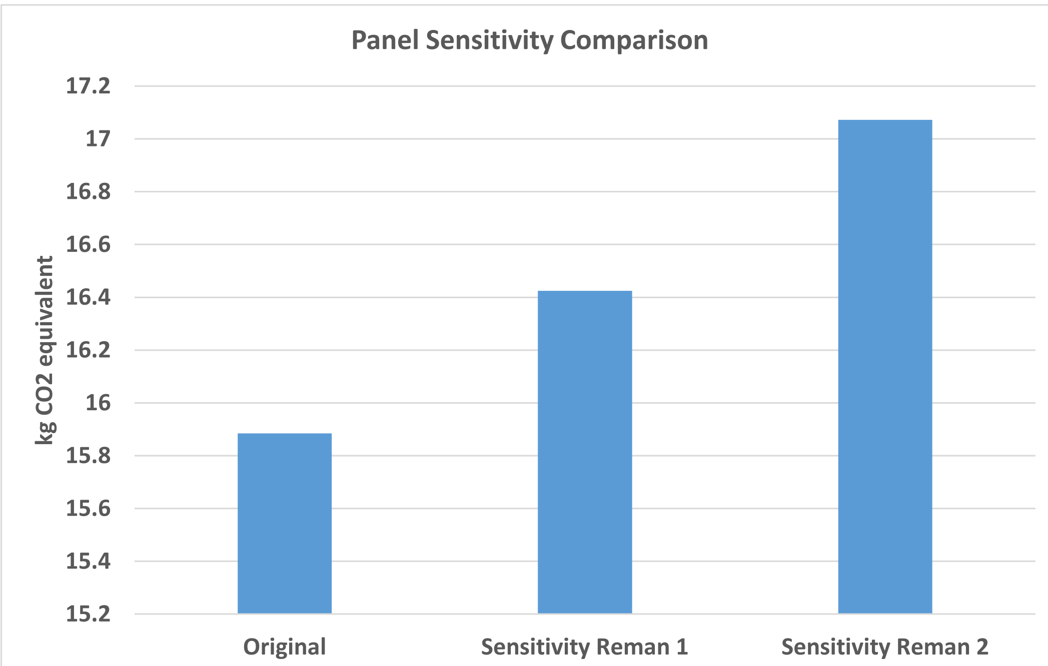

Figure 54: Panel Sensitivity Comparison for Climate Change

The transportation sensitivity analysis looked only at the variation of travel distance for the entire office system. The original travel distance for Davies is a weighted average based on annual sales by state. This sensitivity doubled the travel distance for remanufacturing, which in turn doubled the impact.

Transport	Original			Sensitivity 1	
Office System	**OEM tkm**	**Reman 1 tkm**	**Reman 2 tkm**	**Reman 1 tkm**	**Reman 2 tkm**
Pick up from Customer /EOL	14.7	368	350	736	699
Ship to Customer	110	350	354	699	708

Table 22: Transport Scenarios for Sensitivity Analysis

Figure 55 shows the variation of impact by increasing the total travel distance. One thing to note is the minor variations between the reman 1 and reman 2 for both the original and sensitivity scenarios. The reman 1 pickup from customer is greater than the ship to customer, Table 22. This is due to the indexing of the panels and reduction of the overall office system weight. For reman 2 there is an increase in the ship to customer due to the addition of laminate material to the work surfaces. Though there is a change in the overall office system weight from one life cycle to the next, this provides minimal impact at the single office system level.

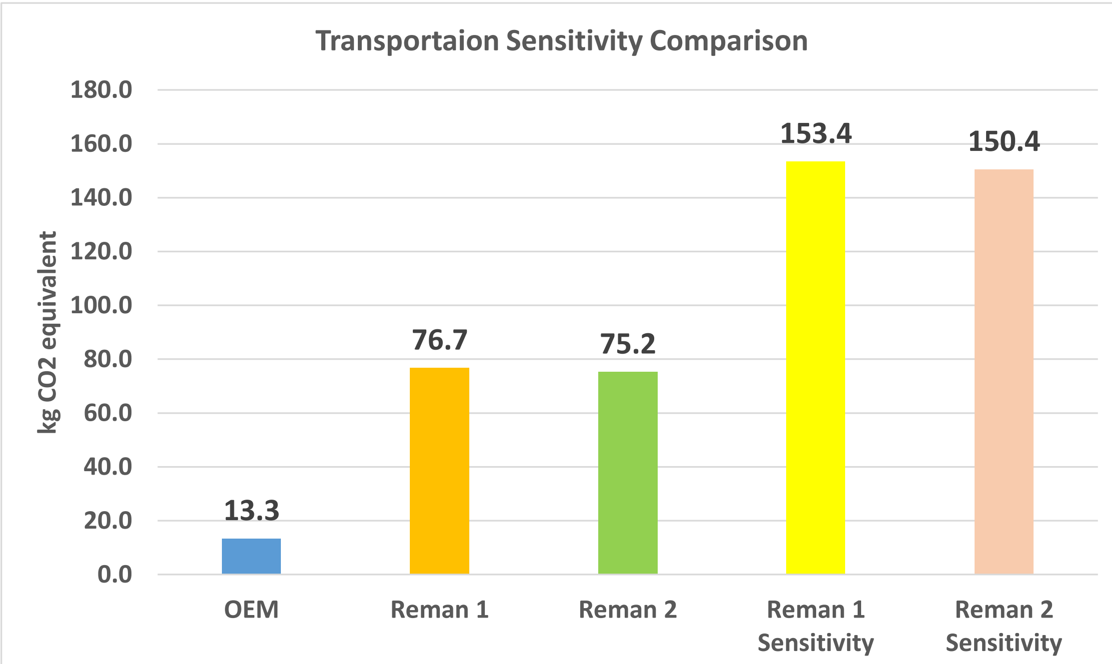

Figure 55: Transportation Sensitivity Comparison for Climate Change

Comparison of the four energy mix scenarios in SimaPro, seen in Figure 56, shows the relative impacts of each. It can be seen that in most categories the New York mix has the least amount of impact while the US average appears to have the greatest impacts in general. The Michigan mix appears to be second behind the US average for impacts.

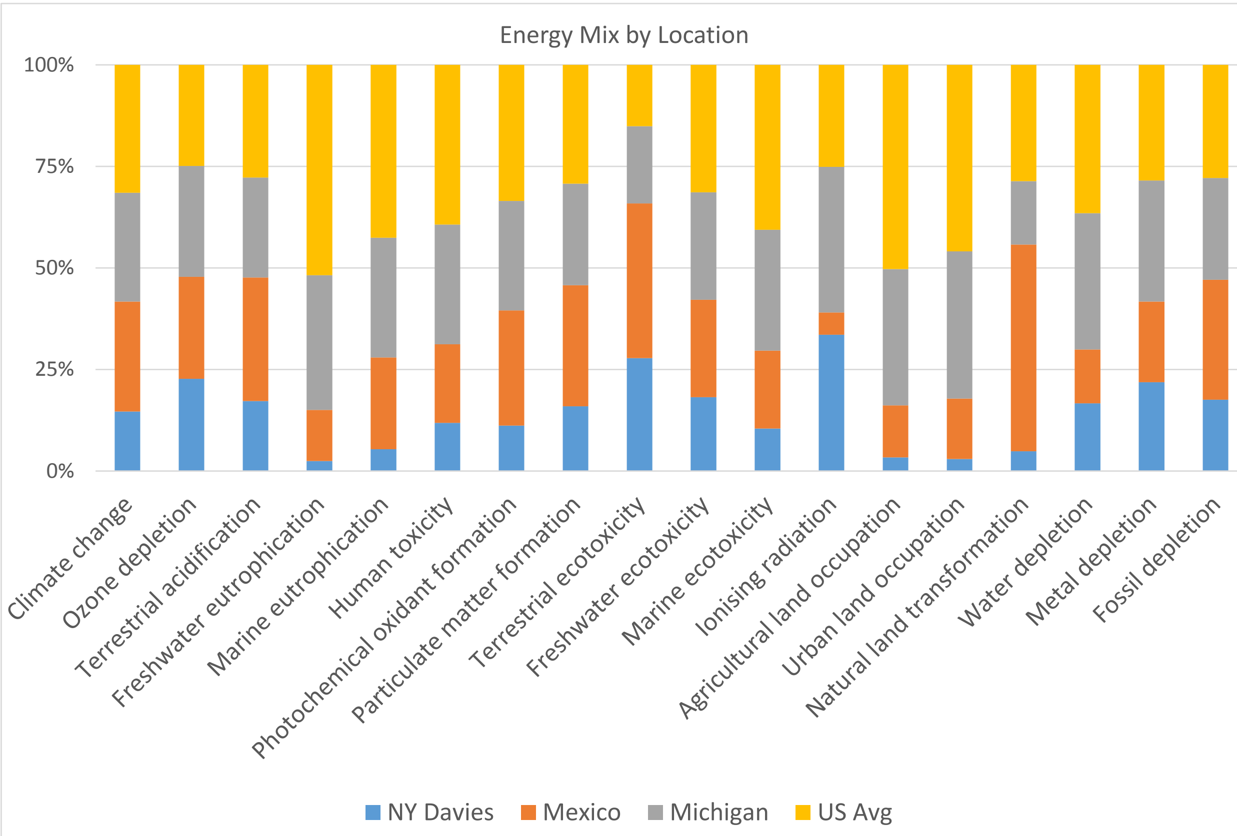

Figure 56: ReCiPe Midpoint Energy Mix Comparison

The sensitivity analysis for energy mix comparison used one representative product, which was a 65 x 48-inch panel that is not indexed during the remanufacturing cycles. Each cycle starts with the OEM and ends with end of life disposition previously defined in this report. This sensitivity used the US average as the baseline, where the assumption is both the OEM and Davies use that energy mix. The other scenarios varied the OEM between the Mexico and Michigan energy mixes while Davies used the New York mix for both. The sensitivity was modeled using both the ReCiPe midpoint and CED methods where results can be seen in Figure 57 and Figure 58. The results indicate that the energy mix does not have a significant impact in the life cycles. This can be attributed to the fact that other contributors outweigh the production energy impacts, such as material production.

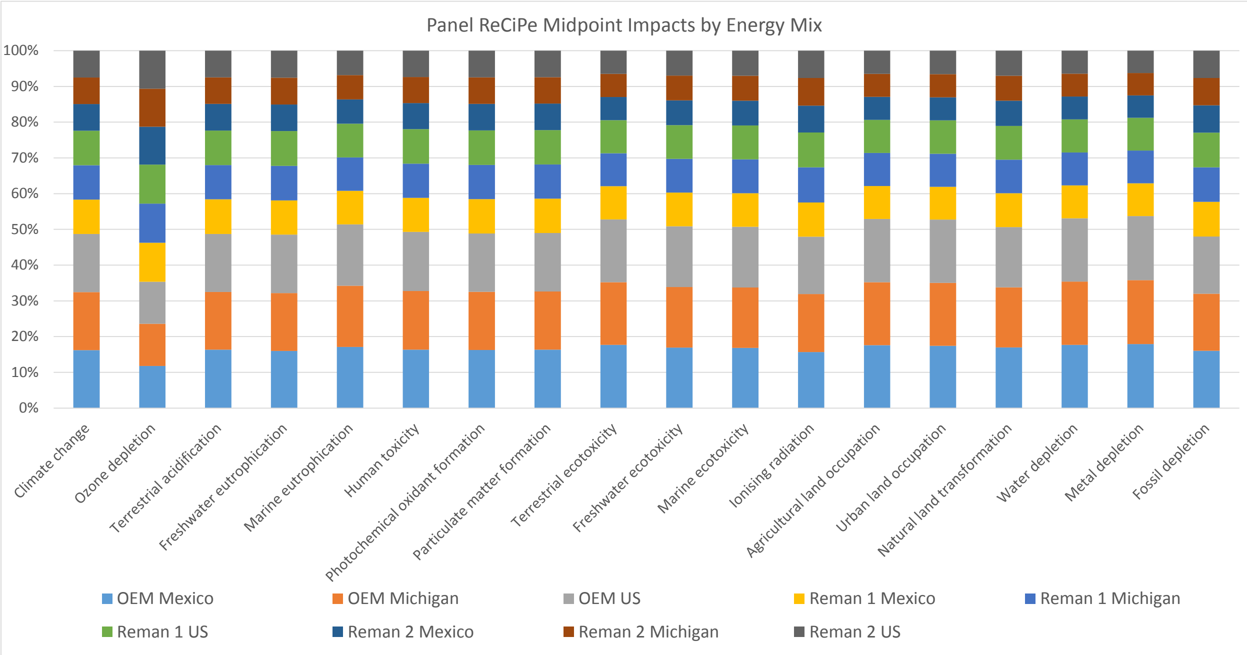

Figure 57: Panel ReCiPe Midpoint Energy Mix Sensitivity by Life Cycle

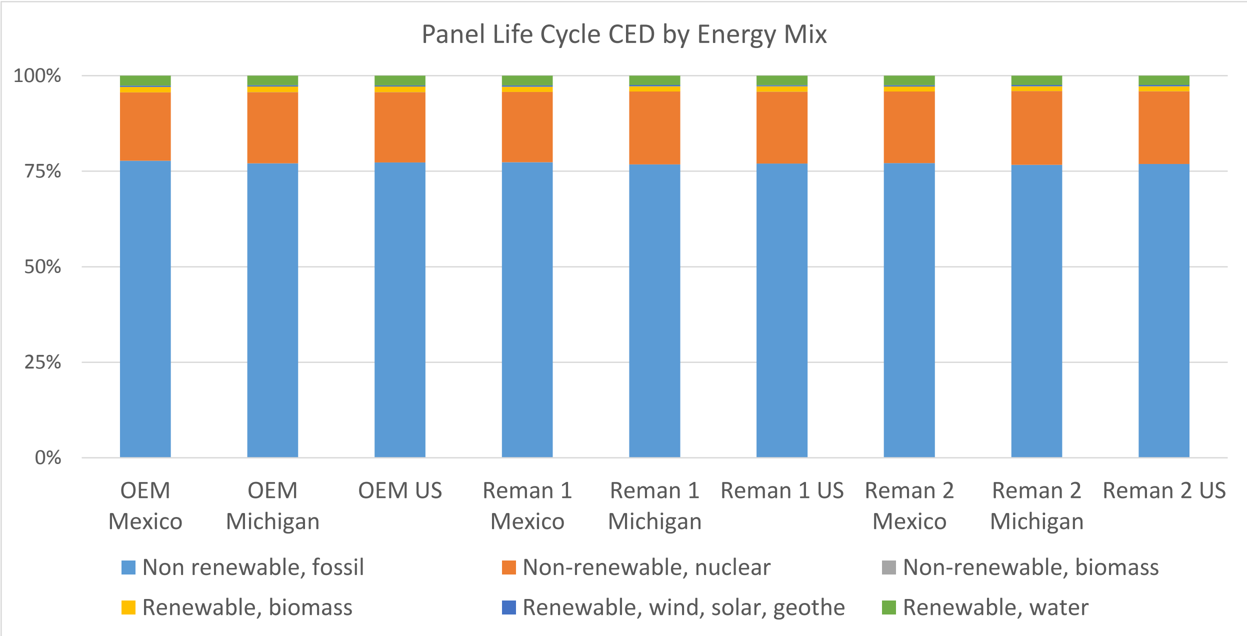

Figure 58: Panel CED Energy Mix Sensitivity by Life Cycle

The results of the environmental impacts for packaging are illustrated in Figure 59. The original OEM packaging from (Dietz 2005), Davies remanufactured packaging and an assumed improved OEM packaging representative of current conditions are compared. Reduction in the use of materials with increased use of recycled and recyclable materials reduces the environmental impacts.

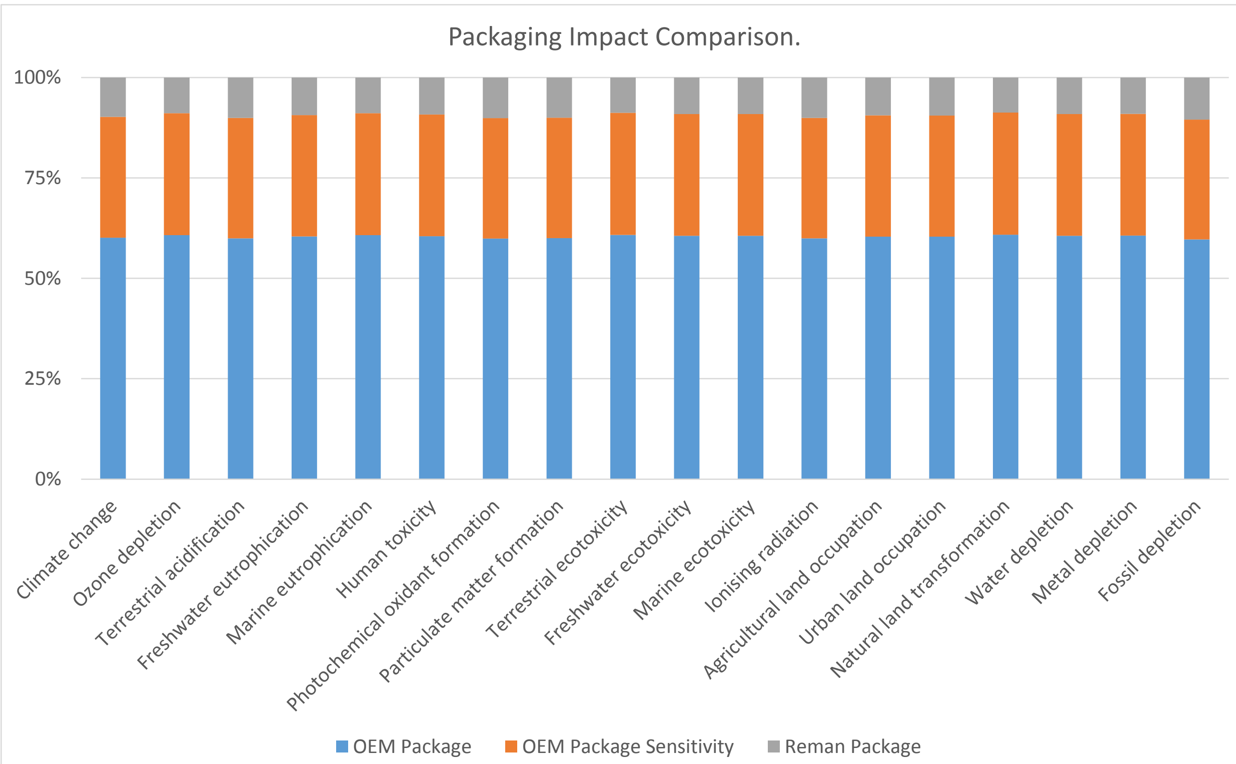

Figure 59: Packaging Impact and Sensitivity

6. Conclusion

It should be noted that the Dietz (2005) study, upon which OEM process models are based, focuses on the Steelcase Answer family of products rather than the Avenir system Davies remanufactures. However, because the Answer and Avenir product families share many of the same components and are produced at the same or similar OEM facility, it is reasonable to expect that they share many of the same manufacturing processes, and that this comparison is thus appropriate in the absence of other adequate OEM data. Physical comparison of the two systems yields myriad similarities, but processes corresponding to patent differences—such as the production of steel support legs in the Answer that are not found on the Avenir system—were carefully omitted in this study's representation of OEM manufacturing processes in order to preserve the accuracy of this comparison.

In this, it should be further noted that only process models drew from the Dietz (2005) study; specific material composition of the Avenir system is recognized to be unique. This data was not therefore modeled on Dietz (2005), but instead collected directly from Avenir core stocks at Davies under the assumption that gross material composition does not change significantly over the lifecycle of office workspace products. This data was then used to build OEM process models using SimaPro software and the Ecoinvent database in order to avoid the potential uncertainties of relying on somewhat dated modeling methodologies. Ultimately, then, the Dietz (2005) study effectively provided only a roadmap for the order and type of manufacturing processes used to make Steelcase products, and was not used to suggest the 2005 OEM Answer product as a wholesale surrogate for the OEM Avenir products in this study. In light of these considerations, adaptation of the OEM Answer manufacturing process from Dietz (2005) as a representation of the OEM Avenir manufacturing process is fundamentally appropriate, though not all elements of imprecision can be eliminated.

This study evaluated the life cycle environmental impacts associated with the manufacturing and remanufacturing of a typical office workspace system, including its various components—the work surface, lateral file, and divider panels. The OEM system, represented by models of known Steelcase manufacturing processes (Dietz 2005) adapted for contemporary product flows, was compared to a remanufactured system with the same configuration and layout built by Davies Office Furniture, Inc. Results of this comparison illustrate the overall environmental life cycle benefits of remanufacturing, and reinforce the notion that product life may be extended through the reuse of materials and components without compromising on cost, quality, or environmental impact. Beyond this, the above evaluations also identify areas in the remanufacturing process that contribute most to environmental impacts, providing new insight for stakeholders seeking to continuously improve these processes.

These assessments suggest that the production of virgin material—especially steel—is responsible for a majority of the impacts attributed to the OEM product. Davies' nearly complete reuse of the steel found in panel frames, file units, and storage pedestals virtually eliminates these impacts during the remanufacturing process, minimizing the remanufactured system's relative impacts in comparison. Davies' material use savings are compounded by their ability to maintain high reuse in work surface cores, primarily constructed from particle board, which can be refaced and relaminated as necessary without undue environmental burden. However, both the OEM process and Davies' remanufacturing process create notable impacts as a result of the powder coating process in which exposed metal components are finished or refinished. While this is a secondary contributor in the OEM process (as steel production is the dominant factor), powder coating represents Davies' single most impactful activity, contributing one and two orders of magnitude more to climate change impacts than electricity use and welding activities, respectively.

Ultimately, these results support the contention that remanufacturing can reduce the overall life cycle environmental impacts of office furniture products when compared with virgin production. Importantly, however, this study also explored subsequent cycles in which previously remanufactured systems were remanufactured a second time. These explorations estimate that subsequent remanufacturing cycles create environmental impacts effectively equivalent to—though in some measures actually even *less* than—the impacts of initial remanufacturing. This, then, suggests that due to the durability of office furniture products, remanufacturing in this case can be made a cyclic endeavor without incurring additional environmental impacts beyond those of a virgin product. Applying this notion in a broader sense, the potential to grow office furniture remanufacturing if its success does not hinge upon the availability of virgin OEM cores creates the possibility that eventually, remanufacturing previously remanufactured products may grow to offset some virgin production rather than simply supplement it, significantly reducing the impacts attributable to the industry market as a whole. This potential is supported by Davies' innovative practice of resizing office system components (typically by decreasing the overall height to promote a more open and collaborative office space), which not only allows Davies to keep up with evolving market trends, but also enables them to customize existing products during remanufacturing to the unique needs of their customers. Access to product options that might not be available from an OEM product offering can thus improve Davies' competitive stance against virgin production, further promoting the benefits of remanufacturing.

It is critical to acknowledge, however, that primary data was not available for the number of remanufacturing life cycles a particular component may have already experienced prior to entering what this study defines as its "Reman 2" lifecycle. The inherent variability of modeling scenarios available is a limiting factor which may impact results in either direction, as products entering "Reman 2" lifecycles may require more or less intense processing depending on how many cycles they had actually previously endured. Data for material fallout and replacement was provided by Davies, where available, to gain some sense of these impacts, but replacement rates for components such as work surface cores and panel tack board for additional remanufacturing cycles could not be determined. To explore the effects of these potential variations, the sensitivity analyses documented in section 5.3 demonstrate the possibility of increased impacts in cases of higher replacement rates, though more data would be required to validate these replacement scenarios. In any case, however, total impacts of systems remanufactured either for the first or second time are likely to remain significantly less than those of OEM production.

In all of this, remanufacturing appears to hold its environmental preferability over virgin production in this study. While these benefits are popularly extrapolated to the industry sector as a whole, it must be stated that the results suggested in this study are specific to this particular case, and are themselves subject to the limitations in data outlined throughout this report. As a result, caution should be taken in using the data and result interpretations presented here; LCA results should not be the only source of a product's environmental profile. Limitations to the availability of OEM data and data quality should be considered when comparing life cycles, and comparisons to other products and other industries, or broad conclusions about the current or future state of remanufacturing economies cannot and should not be drawn from this study alone. The scope of this study is limited only to the specific products, processes, materials, and locations identified herein, which do not themselves necessarily serve as accurate representations of more diverse and complex industrial systems.

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7. Appendix A: Data Sources

Metric	Value	Comments and Data Source
Davies Remanufacturing Facility		
Plant location	Albany, New York	Data collected at Davies by GIS and provided by Davies Staff upon request.
Manufacturing Process energy *Overhead energy Electricity*	See Appendix B.	Equipment energy derived from the OEM LCA (Dietz 2005). Remanufacturing Process times collected while observing each process. Overhead energy at Davies as calculated based on energy bills from august to September 2015.
Main Production/Warehouse	0.00043 kWh.sqft/hr	Overhead based on process area and utility bills provided by Davies
Showroom/Metal/Office	0.00072 kWh.sqft/hr	
Outlet	0.00098 kWh.sqft/hr	
Overhead energy Natural Gas		
Main Production/Warehouse	0.0000824 kWh.sqft/hr	
Showroom/Metal/Office	0.00289 kWh.sqft/hr	
Outlet	NA	
Transportation		
Shipping from client to Davies and then back to client after reman	638 miles (1027 km) one way	This assumes that the office system is recovered from the client and returned to Davies to be remanufactured and returned to the customer. A weighted average used based on client locations and sales dollars.
End of Life		
Recycling	41 km	Assumed Value derived from OEM LCA (Dietz 2005)
MSW	41 km	Assumed Value derived from OEM LCA (Dietz 2005)
Metric	**Value**	**Comments and Data Source**
OEM Office		
OEM plant location	Grand Rapids, Michigan	Dietz 2005
Manufacturing Energy for panel	0.414 kwh/kg	Values derived from the Dietz 2005 study and based on mass. Overhead is included within these values.
Manufacturing Energy for Work Surface	0.7168 kWh/kg	
Manufacturing Energy for panel	0.429 kWh/kg	
Transportation		
To customer	308 km	Dietz 2005
OEM Office EOL		

Metric	Value	Comments and Data Source
Percent Steel recycled	100%	It is assumed the EOL scenarios in the Dietz 2005 study are not representative of today's practices and that all steel is recovered for recycling from today's components at end of life
Landfill	41 km	All remaining materials go to a landfill treatment. (Dietz 2005)

8. Appendix B: Davies Process Description and Intensity

Equipment	kWh/min	cfm
Sanding	0.417	0.17
table saw	0.167	0.03
edgeband	0.5	0.08
pneumatic hand tools	0	24.33
Drilling Steel	0.016	0.00
Hot-melt station (fabric)	0.31	35
Hot-laminating press (wood)	0.53	17
Hand tools	0.007	N/A
Roller press	0.42	25

Table 23: Equipment energy and compressed air use [38]

Process Name	Process Description	Equipment Used	Reman 1 process time (min)
Disassembly	Remove drawers, screws tracks and other hardware. Pound out small dents and dings	Cordless Drill	1.0000
		Air powered hand buffer/grinder	0.333
Paint Prep	Buff, grind, sand surface blemishes, bondo large nicks and dents. Clean off surfaces. Mask any surfaces such as handles and openings	Air powered hand buffer/grinder	4.000
		Degrease Drawer	NA
		Hand sander	Incl. above
Paint and Powder coat	Hang work pieces from overhead conveyor line, final wipe down with tac cloth, automatic and	Conveyor line	
		Final wipe down while on line with tac cloth	
		Automated and Manual spray guns	

[38] Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005

Process Name	Process Description	Equipment Used	Reman 1 process time (min)
	manual powder coating then oven curing.	Spray booth exhaust hood	29.933
		NG Oven	
Rework	10% rework rate where product has to be re powder coated. The workpiece is baked in a bake off oven at high temp to remove coatings and then goes back to prep.		120.000
Final Assembly	Assemble components, hardware drawers into shell and test functionality.	Electric Screw Gun	1.0000

Table 24: File and Pedestal Remanufacturing Process

Process Name	Process Description	Equipment Used	Reman 1 process time (min)
Work Surface Preparation	New pressboard plug to fill grommets and electrical outlet holes.		NA
			NA
	Remove old edge banding, patch nicks and dings, scuff surface with power sander	Makita belt sander	4.9667
		Makita belt sander	
	lift work surface	Suction lift 250 lb	0.167
Laminate preparation	New Laminate Cut for work surface from large laminate sheets	Table Saw	0.019
Work Surface Lamination	Blow off dust from surfaces with compressed air Spray adhesive on work surface and laminate, apply laminate to	Spray Gun	0.367
		Exhaust hood booth	0.367
		IR oven	2

Process Name	Process Description	Equipment Used	Reman 1 process time (min)
	work surface, roller press laminate onto work surface after IR oven	Conveyor motor	3.717
		Mechanical roller Press	0.133
		Air nozzle	0.083
Post Forming	Laminate is mechanically pressed onto edges of work surface one side at a time, when one edge is complete worker uses an air lift suction to move work surface back to beginning for other side excess laminate trimmed mechanically and suctioned into dust collector	Air Lift	0.167
		Post Former	1.200
Edge Banding	Excess laminate is trimmed with a router, edges are sanded with a small electric belt sander, the work surface is then moved with 250 lb air lift to the edge bander where adhesive and pvc edge banding applied on each side. After one side complete the work surface is moved on a roller conveyor to the beginning for the second side.	Router	0.317
		Makita belt sander	0.217
		Holtzer Edge Bander	0.959
			0.959
Staging and Packaging	Work surfaces are manual wiped down, cleaned and rough edges finished. They are then packages with foam corner protectors on alternate work surfaces in the stack, and plastic wrapped or foam and plastic wrapped.	Air lift	0.167

Table 25: Work Surface Remanufacturing Process

Process Name	Process Description	Equipment Used	Reman 1 process time (min)
Panel Disassembly	Remove external hardware, top cap and side rails, remove 2 foam strips, remove panel, cut off fabric, remove	Air powered Screw gun	0.33
		Electric Screw Gun	na
Metal Indexing	Resizing external and internal steel frames, by cutting and welding. Drill out connecting rivets of internal frame.	Band Saw	1.50
		Air powered grinder	0.50
		Welder	16.00 (inches)
		Drill press	1.08

Process Name	Process Description	Equipment Used	Reman 1 process time (min)
Acoustical panel indexing	Cut down acoustical panel and batting material	Table Saw	0.17
Upholstery	Cut Upholstery fabric 2 inches oversized on all edges, apply adhesive to fabric and internal frames. Mount fabric to internal frame and fiber board Trim excess fabric	Hand cut fabric	0.00
		Adhesive Sprayer	0.67
		Exhaust Hood	2.00
		IR oven cure	3.72
		Conveyor	
Powder Coating	Powder coat kick plates and top cap for panels and other metal trim and hardware (All hardware for 1 cube can hang on 1 rack. See Images		29.33
		Conveyor Rack	
		Automatic Powder Coating guns arms x4	
		Manual pc guns	
		NG oven	
Final Assembly	Assemble all components into the final panel	Electric Screw Gun	0.08

Table 26: Panel Remanufacturing Process

9. Appendix C: Office System Life Cycle Inventory Comparison

Results:	Inventory
Product 1:	1 p OEM Office System (of project ..Davies LCA)
Product 2:	1 p Reman 1 Office System (of project ..Davies LCA)
Product 3:	1 p Reman 2 Office System (of project ..Davies LCA)
Method:	ReCiPe Midpoint (H) V1.11 / Europe Recipe H
Indicator:	Inventory
Compartment:	All compartments
Per sub-compartment:	No
Default units:	No
Exclude infrastructure processes:	No
Exclude long-term emissions:	No
Sorted on item:	Main category
Sort order:	Ascending

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
1	Aluminium	Raw	g	794.31889	27.20261	57.0289
2	Anhydrite	Raw	mg	119.71652	75.27315	75.55038
3	Barite	Raw	g	414.03725	73.26839	80.0664
4	Basalt	Raw	g	301.66186	7.793989	11.08098
5	Borax	Raw	kg	1.1835895	5.84E-06	5.98E-06
6	Bromine	Raw	g	1.107671	0.001533	0.001572
7	Cadmium	Raw	mg	61.686172	12.1917	10.19923
8	Calcite	Raw	kg	88.661855	0.238078	5.683187
9	Carbon dioxide, in air	Raw	kg	188.18833	9.514058	14.44471
10	Carbon, organic, in soil or biomass stock	Raw	mg	752.7388	222.8417	226.5307
11	Chromium	Raw	kg	4.6546072	-0.35618	0.007624
12	Chrysotile	Raw	mg	205.65722	90.0588	90.87919
13	Cinnabar	Raw	mg	51.54126	40.02767	40.81276
14	Clay, bentonite	Raw	kg	2.4316527	-0.17992	0.006221
15	Clay, unspecified	Raw	kg	19.148655	1.541783	1.91672

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No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
16	Coal, brown	Raw	kg	128.43046	19.86563	22.26801
17	Coal, hard	Raw	kg	294.94261	4.12994	17.44095
18	Cobalt	Raw	mg	6.2654966	3.801187	3.80568
19	Colemanite	Raw	kg	8.1555941	0.358557	0.358565
20	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore	Raw	g	19.328854	2.836742	3.136222
21	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore	Raw	g	105.34628	14.30309	15.93222
22	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore	Raw	g	27.944607	3.7941	4.226248
23	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore	Raw	g	138.98361	19.00721	21.15152
24	Diatomite	Raw	µg	26.002158	4.279331	4.059062
25	Dolomite	Raw	g	524.89318	-37.5224	0.984329
26	Energy, gross calorific value, in biomass	Raw	MMBTU	1.9594721	0.09978	0.151267
27	Energy, gross calorific value, in biomass, primary forest	Raw	kJ	52.186823	15.44945	15.70521
28	Energy, kinetic (in wind), converted	Raw	MJ	52.739284	8.172975	9.158813
29	Energy, potential (in hydropower reservoir), converted	Raw	MJ	607.18695	46.98859	69.12471
30	Energy, solar, converted	Raw	kJ	829.73063	120.1677	133.7426
31	Feldspar	Raw	µg	768.40718	233.651	235.4231
32	Fluorine	Raw	g	1.8429786	0.103092	0.161959
33	Fluorine, 4.5% in apatite, 3% in crude ore	Raw	g	13.676059	0.048747	0.074842
34	Fluorspar	Raw	g	95.797543	9.037395	9.44942
35	Gallium	Raw	µg	2.2253553	0.333754	0.373512
36	Gas, mine, off-gas, process, coal mining/m3	Raw	m3	2.6697101	0.007485	0.13751

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
37	Gas, natural/m3	Raw	m3	155.92311	37.60626	40.0215
38	Gold	Raw	µg	714.16716	314.8363	317.9187
39	Gold, Au 1.1E-4%, Ag 4.2E-3%, in ore	Raw	µg	325.2638	143.3906	144.7945
40	Gold, Au 1.3E-4%, Ag 4.6E-5%, in ore	Raw	µg	596.46333	262.9473	265.5217
41	Gold, Au 2.1E-4%, Ag 2.1E-4%, in ore	Raw	mg	1.0908145	0.480879	0.485587
42	Gold, Au 4.3E-4%, in ore	Raw	µg	270.34812	119.1814	120.3482
43	Gold, Au 4.9E-5%, in ore	Raw	µg	647.51812	285.4545	288.2492
44	Gold, Au 6.7E-4%, in ore	Raw	mg	1.0024632	0.44193	0.446257
45	Gold, Au 7.1E-4%, in ore	Raw	mg	1.1303813	0.498322	0.503201
46	Gold, Au 9.7E-4%, Ag 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore	Raw	µg	67.734821	29.86049	30.15284
47	Granite	Raw	µg	412.57382	217.5363	217.5724
48	Gravel	Raw	kg	161.75621	12.24512	14.82074
49	Gypsum	Raw	mg	95.121237	16.32702	19.18245
50	Indium	Raw	mg	1.138376	0.219757	0.188524
51	Iodine	Raw	mg	102.31669	0.34238	0.350928
52	Iron	Raw	kg	193.75543	-15.2239	-0.16517
53	Kaolinite	Raw	g	3.78802	0.07045	0.2355
54	Kieserite	Raw	mg	16.239063	2.008114	2.41284
55	Lead	Raw	g	10.519256	1.039723	0.989053
56	Lithium	Raw	mg	1.299723	0.00701	0.007181
57	Magnesite	Raw	kg	2.6268074	-0.20628	-0.00186
58	Magnesium	Raw	mg	9.1053238	1.40667	1.591486
59	Manganese	Raw	kg	3.2712832	-0.27137	-0.01214
60	Metamorphous rock, graphite containing	Raw	mg	642.53049	64.25542	75.20799
61	Molybdenum	Raw	g	71.828257	-5.93779	-0.24987
62	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore	Raw	g	2.5828299	0.353224	0.393073

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
63	Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore	Raw	mg	367.05458	49.83579	55.51209
64	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore	Raw	g	35.590854	-2.9416	-0.12333
65	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore	Raw	g	1.3450014	0.182614	0.203413
66	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore	Raw	g	3.4022904	0.949209	1.015071
67	Nickel, 1.98% in silicates, 1.04% in crude ore	Raw	kg	12.072975	-0.9279	0.015433
68	Occupation, arable	Raw	m2a	13.362599	0	0
69	Occupation, arable, non-irrigated	Raw	m2a	0.75085955	0.015119	0.016195
70	Occupation, construction site	Raw	cm2a	935.08196	67.58675	100.77
71	Occupation, dump site	Raw	m2a	2.7063251	0.009381	0.122363
72	Occupation, dump site, benthos	Raw	cm2a	478.75806	86.69969	95.05599
73	Occupation, forest, intensive	Raw	m2a	14.280988	12.27929	12.29432
74	Occupation, forest, intensive, normal	Raw	m2a	64.126117	3.044126	4.984479
75	Occupation, forest, intensive, short-cycle	Raw	cm2a	130.90818	38.75421	39.39577
76	Occupation, industrial area	Raw	m2a	1.1498144	0.021786	0.073002
77	Occupation, industrial area, benthos	Raw	mm2a	438.48414	81.04255	88.74089
78	Occupation, industrial area, built up	Raw	m2a	2.1178678	0.021833	0.07074
79	Occupation, industrial area, vegetation	Raw	m2a	2.1291706	0.011672	0.025213
80	Occupation, mineral extraction site	Raw	m2a	0.94034444	0.039596	0.070409

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
81	Occupation, permanent crop, fruit, intensive	Raw	cm2a	232.50692	56.41054	57.25589
82	Occupation, shrub land, sclerophyllous	Raw	cm2a	597.46276	23.47041	49.92555
83	Occupation, traffic area, rail network	Raw	m2a	0.2007288	0.015648	0.024399
84	Occupation, traffic area, rail/road embankment	Raw	m2a	0.18152861	0.014151	0.022065
85	Occupation, traffic area, road embankment	Raw	m2a	0.89906222	0.238046	0.25655
86	Occupation, traffic area, road network	Raw	m2a	2.1120507	0.028592	0.053462
87	Occupation, urban, discontinuously built	Raw	cm2a	209.41521	0.352165	0.365873
88	Occupation, water bodies, artificial	Raw	m2a	0.90043636	0.101795	0.117571
89	Occupation, water courses, artificial	Raw	m2a	0.65557629	0.025239	0.05308
90	Oil, crude	Raw	kg	69.602428	15.35446	16.33851
91	Olivine	Raw	mg	78.33572	51.04634	51.55199
92	Palladium, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	µg	128.42952	36.33792	37.67342
93	Palladium, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	µg	308.63923	87.32655	90.53601
94	Peat	Raw	g	36.700369	17.67184	17.74953
95	Phosphorus	Raw	g	54.902264	0.298122	0.402541
96	Phosphorus, 18% in apatite, 4% in crude ore	Raw	g	7.3719144	0.41237	0.647838
97	Platinum, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	µg	7.7432773	1.11183	1.237678
98	Platinum, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni	Raw	µg	27.758994	3.985817	4.436969

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
	3.7E-2%, Cu 5.2E-2% in ore					
99	Potassium chloride	Raw	g	381.55122	47.30805	48.08517
100	Rhenium	Raw	µg	2.0945242	0.244344	0.276768
101	Rhodium, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in ore	Raw	µg	2.3722573	0.307899	0.34691
102	Rhodium, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in ore	Raw	µg	7.4301766	0.964373	1.086563
103	Sand	Raw	g	15.004699	11.29333	11.53527
104	Shale	Raw	mg	339.08566	213.1845	213.9694
105	Silver, 0.007% in sulfide, Ag 0.004%, Pb, Zn, Cd, In	Raw	mg	7.4186143	3.199427	3.234729
106	Silver, 3.2ppm in sulfide, Ag 1.2ppm, Cu and Te, in crude ore	Raw	mg	5.2951668	2.282712	2.30796
107	Silver, Ag 2.1E-4%, Au 2.1E-4%, in ore	Raw	µg	488.64131	210.7239	213.0504
108	Silver, Ag 4.2E-3%, Au 1.1E-4%, in ore	Raw	mg	1.1160002	0.481269	0.486582
109	Silver, Ag 4.6E-5%, Au 1.3E-4%, in ore	Raw	mg	1.0938673	0.471724	0.476932
110	Silver, Ag 9.7E-4%, Au 9.7E-4%, Zn 0.63%, Cu 0.38%, Pb 0.014%, in ore	Raw	µg	721.79333	311.2694	314.706
111	Sodium chloride	Raw	kg	21.39597	13.04224	13.23689
112	Sodium nitrate	Raw	µg	1.104184	0.338377	0.349946
113	Sodium sulfate	Raw	g	4.7195893	1.228296	1.313018
114	Stibnite	Raw	µg	2.7021854	0.444715	0.421824
115	Sulfur	Raw	g	149.12738	7.90282	7.836862
116	Talc	Raw	g	6.2268921	5.099934	5.122517
117	Tantalum	Raw	mg	5.8191597	2.520164	2.547384
118	Tellurium	Raw	µg	794.28835	342.4125	346.1998
119	Tin	Raw	g	1.8820527	0.170183	0.184943

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
120	TiO2, 54% in ilmenite, 2.6% in crude ore	Raw	kg	1.1687961	0.608237	0.608563
121	TiO2, 95% in rutile, 0.40% in crude ore	Raw	µg	491.61995	246.6368	245.9759
122	Transformation, from arable	Raw	m2	13.363274	5.29E-05	6.80E-05
123	Transformation, from arable, non-irrigated	Raw	m2	1.3140875	0.027782	0.029768
124	Transformation, from arable, non-irrigated, fallow	Raw	mm2	96.243628	3.230756	6.84999
125	Transformation, from dump site, inert material landfill	Raw	cm2	30.639165	6.857898	6.900629
126	Transformation, from dump site, residual material landfill	Raw	cm2	84.848244	-3.11872	2.740062
127	Transformation, from dump site, sanitary landfill	Raw	mm2	147.42824	95.01578	32.88806
128	Transformation, from dump site, slag compartment	Raw	mm2	239.50955	0.972818	1.115013
129	Transformation, from forest	Raw	cm2	977.45268	145.298	161.9576
130	Transformation, from forest, extensive	Raw	sq.in	905.88218	167.8986	190.4169
131	Transformation, from forest, intensive, clear-cutting	Raw	mm2	467.53128	138.4085	140.6998
132	Transformation, from industrial area	Raw	cm2	13.052673	2.279086	2.497015
133	Transformation, from industrial area, benthos	Raw	mm2	4.0242167	0.861767	0.935294
134	Transformation, from industrial area, built up	Raw	mm2	1.8540635	0.145792	0.229749
135	Transformation, from industrial area, vegetation	Raw	mm2	3.1628145	0.248704	0.391926

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
136	Transformation, from mineral extraction site	Raw	cm2	103.71472	9.108919	12.21765
137	Transformation, from pasture and meadow	Raw	cm2	248.26304	10.68775	21.09263
138	Transformation, from pasture and meadow, intensive	Raw	cm2	10.729632	0.22669	0.242902
139	Transformation, from sea and ocean	Raw	cm2	479.85157	86.81033	95.17654
140	Transformation, from shrub land, sclerophyllous	Raw	cm2	153.05095	6.13844	12.88237
141	Transformation, from tropical rain forest	Raw	mm2	467.53128	138.4085	140.6998
142	Transformation, from unknown	Raw	sq.in	282.93762	2.713474	10.52627
143	Transformation, to arable	Raw	m2	13.375997	0.002209	0.002516
144	Transformation, to arable, non-irrigated	Raw	m2	1.3158322	0.027804	0.029793
145	Transformation, to arable, non-irrigated, fallow	Raw	mm2	174.07118	9.155964	14.43302
146	Transformation, to dump site	Raw	cm2	195.66471	0.800067	8.69803
147	Transformation, to dump site, benthos	Raw	cm2	478.75806	86.69969	95.05599
148	Transformation, to dump site, inert material landfill	Raw	cm2	30.639165	6.857898	6.900629
149	Transformation, to dump site, residual material landfill	Raw	cm2	84.848856	-3.11868	2.740105
150	Transformation, to dump site, sanitary landfill	Raw	mm2	147.42824	95.01578	32.88806
151	Transformation, to dump site, slag compartment	Raw	mm2	239.50955	0.972818	1.115013
152	Transformation, to forest	Raw	cm2	134.80052	5.077036	10.97058
153	Transformation, to forest, intensive	Raw	cm2	950.94121	817.6365	818.6374
154	Transformation, to forest, intensive, clear-cutting	Raw	mm2	467.53128	138.4085	140.6998

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
155	Transformation, to forest, intensive, normal	Raw	sq.in	748.0541	38.56891	60.70515
156	Transformation, to forest, intensive, short-cycle	Raw	mm2	467.53128	138.4085	140.6998
157	Transformation, to heterogeneous, agricultural	Raw	cm2	46.565066	7.010468	7.787862
158	Transformation, to industrial area	Raw	cm2	233.31629	0.985508	12.12483
159	Transformation, to industrial area, benthos	Raw	mm2	109.35405	11.06547	12.05676
160	Transformation, to industrial area, built up	Raw	cm2	413.01321	4.944855	14.80713
161	Transformation, to industrial area, vegetation	Raw	cm2	428.74315	2.651576	5.382581
162	Transformation, to mineral extraction site	Raw	sq.in	184.22963	19.3691	24.22995
163	Transformation, to pasture and meadow	Raw	mm2	730.08432	133.8713	146.2295
164	Transformation, to permanent crop, fruit, intensive	Raw	mm2	327.30313	79.40988	80.59989
165	Transformation, to sea and ocean	Raw	mm2	4.0242167	0.861767	0.935294
166	Transformation, to shrub land, sclerophyllous	Raw	cm2	119.35679	4.699069	9.980722
167	Transformation, to traffic area, rail network	Raw	mm2	464.2945	36.19337	56.43674
168	Transformation, to traffic area, rail/road embankment	Raw	mm2	422.40313	32.92781	51.34471
169	Transformation, to traffic area, road embankment	Raw	cm2	65.231173	16.12742	17.53103
170	Transformation, to traffic area, road network	Raw	cm2	232.833	4.010254	7.885284
171	Transformation, to unknown	Raw	cm2	29.543779	2.053925	2.84561

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
172	Transformation, to urban, discontinuously built	Raw	mm2	417.1416	0.70149	0.728795
173	Transformation, to water bodies, artificial	Raw	cm2	70.502964	7.293941	8.631414
174	Transformation, to water courses, artificial	Raw	cm2	76.619725	3.038372	6.311897
175	Ulexite	Raw	mg	98.945207	16.15685	17.96513
176	Uranium	Raw	g	6.1528328	0.977795	1.068838
177	Vermiculite	Raw	mg	521.07016	3.670469	4.566597
178	Volume occupied, final repository for low-active radioactive waste	Raw	cm3	11.704769	1.690554	1.879409
179	Volume occupied, final repository for radioactive waste	Raw	cm3	2.8857475	0.423915	0.472257
180	Volume occupied, reservoir	Raw	m3y	7.3097215	1.02917	1.144149
181	Volume occupied, underground deposit	Raw	cm3	40.75011	8.06524	9.538492
182	Water, cooling, unspecified natural origin/m3	Raw	m3	19.356059	3.99502	4.196977
183	Water, lake	Raw	dm3	548.74774	3.86557	4.808778
184	Water, river	Raw	m3	5.7510749	0.367366	0.427629
185	Water, salt, ocean	Raw	dm3	433.79489	76.00445	84.29693
186	Water, salt, sole	Raw	dm3	511.71208	5.614395	6.297185
187	Water, turbine use, unspecified natural origin	Raw	Ml	5.5837176	0.254005	0.4907
188	Water, unspecified natural origin/m3	Raw	m3	4.3443917	0.145217	0.402594
189	Water, well, in ground	Raw	m3	7.3251175	0.080842	0.108056
190	Wood, hard, standing	Raw	dm3	50.0649	0.898019	2.31961
191	Wood, primary forest, standing	Raw	cm3	4.8408191	1.433082	1.456806
192	Wood, soft, standing	Raw	dm3	151.69197	9.923339	13.8681
193	Wood, unspecified, standing/m3	Raw	cm3	31.703993	23.71522	24.20861

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
194	Zinc	Raw	g	157.87027	12.5824	13.79753
195	Zirconium	Raw	mg	7.8121361	3.437586	3.471609
196	1-Butanol	Air	µg	38.943652	0.007533	0.007866
197	1-Pentanol	Air	µg	24.564285	0.132491	0.135711
198	1-Pentene	Air	µg	18.562721	0.100121	0.102555
199	1-Propanol	Air	µg	341.93012	2.491742	2.705839
200	1,4-Butanediol	Air	µg	116.15712	0.865209	0.874921
201	2-Aminopropanol	Air	µg	24.098408	0.001784	0.002009
202	2-Butene, 2-methyl-	Air	ng	4.1174492	0.022208	0.022748
203	2-Methyl-1-propanol	Air	µg	130.41497	0.23228	0.238085
204	2-Nitrobenzoic acid	Air	µg	53.581075	0.001613	0.001982
205	2-Propanol	Air	mg	35.445905	15.58382	15.73619
206	Acenaphthene	Air	µg	11.166818	0.697583	0.612112
207	Acetaldehyde	Air	mg	239.18803	66.67875	69.85796
208	Acetic acid	Air	g	3.835775	2.101536	2.127946
209	Acetone	Air	mg	189.89481	42.79312	45.50907
210	Acetonitrile	Air	µg	508.30001	150.4778	152.9688
211	Acrolein	Air	mg	6.4009347	0.408047	0.352962
212	Acrylic acid	Air	µg	91.466449	40.32194	40.71686
213	Actinides, radioactive, unspecified	Air	Bq	40.740645	2.226986	1.824206
214	Aerosols, radioactive, unspecified	Air	Bq	3.5967678	0.421866	0.45069
215	Aldehydes, unspecified	Air	mg	78.656462	23.28336	23.2477
216	Aluminium	Air	g	74.155041	-0.28959	3.384135
217	Ammonia	Air	g	94.308354	8.074792	10.05229
218	Ammonium carbonate	Air	mg	1.1354421	0.144825	0.157172
219	Aniline	Air	µg	152.75518	0.558312	0.571925
220	Anthranilic acid	Air	µg	41.250786	0.00118	0.001449
221	Antimony	Air	mg	546.91499	28.93587	29.17624
222	Antimony-124	Air	µBq	12.400202	1.598386	1.830431
223	Antimony-125	Air	µBq	129.40652	16.68049	19.10208
224	Argon-41	Air	kBq	1.1314777	0.179683	0.202594
225	Arsenic	Air	mg	558.12132	24.90798	35.28595

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
226	Arsine	Air	ng	1.0661619	0.470005	0.474609
227	Barium	Air	mg	157.74592	8.174415	13.91377
228	Barium-140	Air	mBq	8.4177016	1.085041	1.242562
229	Benzal chloride	Air	ng	21.501826	1.171507	0.958027
230	Benzaldehyde	Air	µg	251.6548	42.10825	43.32623
231	Benzene	Air	g	11.669331	3.81358	3.951109
232	Benzene, 1-methyl-2-nitro-	Air	µg	46.268567	0.001393	0.001712
233	Benzene, 1,2-dichloro-	Air	µg	196.87687	0.249307	0.261111
234	Benzene, ethyl-	Air	mg	92.13578	14.86185	16.21737
235	Benzene, hexachloro-	Air	mg	1.8295476	-0.14135	-0.00113
236	Benzene, pentachloro-	Air	µg	74.73441	0.924927	1.035912
237	Benzo(a)pyrene	Air	mg	11.569953	0.618323	1.132516
238	Beryllium	Air	mg	1.9617358	0.075064	0.143789
239	Boron	Air	g	3.6706468	0.502188	0.576672
240	Boron trifluoride	Air	pg	14.591193	6.43236	6.49536
241	Bromine	Air	mg	469.46136	57.40867	64.90033
242	Butadiene	Air	µg	16.899455	0.550197	0.557597
243	Butane	Air	g	7.9190221	1.312789	1.434356
244	Butene	Air	mg	102.8815	8.530469	9.717115
245	Butyrolactone	Air	ng	553.05623	241.8502	244.329
246	Cadmium	Air	mg	150.57586	10.32219	11.47712
247	Calcium	Air	g	4.4189522	0.482266	0.582921
248	Carbon-14	Air	kBq	8.8670834	1.396061	1.572422
249	Carbon dioxide, biogenic	Air	kg	52.725388	5.748862	5.797203
250	Carbon dioxide, fossil	Air	tn.lg	1.0623844	0.130076	0.157769
251	Carbon dioxide, land transformation	Air	g	41.035223	6.567817	6.993054
252	Carbon disulfide	Air	g	3.62831	0.099693	0.268425
253	Carbon monoxide, biogenic	Air	g	17.380821	2.129564	2.323428
254	Carbon monoxide, fossil	Air	kg	5.9008293	-0.31581	0.116538
255	Cerium-141	Air	mBq	2.0406416	0.263039	0.301225
256	Cesium-134	Air	µBq	97.733598	12.59786	14.42675

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
257	Cesium-137	Air	mBq	1.732499	0.223319	0.255739
258	Chloramine	Air	µg	144.17906	0.46715	0.478885
259	Chlorine	Air	g	15.287103	9.66151	9.789706
260	Chloroacetic acid	Air	mg	4.0026888	0.002134	0.002907
261	Chloroform	Air	mg	2.7762711	0.159328	0.142363
262	Chlorosilane, trimethyl-	Air	µg	150.66987	4.574758	6.205687
263	Chlorosulfonic acid	Air	µg	37.17027	0.011663	0.014227
264	Chromium	Air	g	16.272254	-1.16053	0.057126
265	Chromium-51	Air	µBq	130.76394	16.85547	19.30245
266	Chromium VI	Air	mg	403.48596	-29.7004	1.382294
267	Cobalt	Air	mg	247.51274	-10.354	6.706401
268	Cobalt-58	Air	µBq	182.09418	23.47193	26.87946
269	Cobalt-60	Air	mBq	1.6086327	0.207353	0.237455
270	Copper	Air	g	1.608646	0.058613	0.121579
271	Cumene	Air	g	8.4067383	4.140481	4.143456
272	Cyanide	Air	mg	362.98314	-0.77934	12.65803
273	Cyanoacetic acid	Air	µg	30.440559	0.009552	0.011652
274	Diethylamine	Air	µg	75.081485	0.248883	0.255052
275	Dimethyl malonate	Air	µg	38.172967	0.011978	0.014611
276	Dinitrogen monoxide	Air	g	43.669642	10.74268	11.0421
277	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	µg	5.5585474	3.399813	3.6031
278	Dipropylamine	Air	µg	34.101574	0.158018	0.161827
279	Ethane	Air	g	26.677121	4.925258	5.493169
280	Ethane, 1,1-difluoro-, HFC-152a	Air	µg	289.4141	43.36384	48.52182
281	Ethane, 1,1,1-trichloro-, HCFC-140	Air	µg	393.76355	21.52399	17.63105
282	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	mg	34.274024	7.415606	6.134909
283	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	µg	4.340961	1.913663	1.932406
284	Ethane, 1,2-dichloro-	Air	mg	267.51466	147.2394	150.7319

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
285	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	mg	6.1780031	0.705582	0.752173
286	Ethane, hexafluoro-, HFC-116	Air	mg	7.3806542	0.984481	1.160446
287	Ethanol	Air	mg	231.52292	37.21365	41.11159
288	Ethene	Air	g	5.280787	0.159666	0.499245
289	Ethene, chloro-	Air	mg	133.90207	72.16049	73.85455
290	Ethene, tetrachloro-	Air	g	14.465398	4.64E-05	3.80E-05
291	Ethyl acetate	Air	mg	165.40719	72.75825	73.48186
292	Ethyl cellulose	Air	µg	332.03263	146.3824	147.8155
293	Ethylamine	Air	µg	234.88174	0.11998	0.124275
294	Ethylene diamine	Air	µg	189.48218	2.514626	2.588285
295	Ethylene oxide	Air	mg	39.148357	30.41336	30.31255
296	Ethyne	Air	mg	310.27304	-15.2408	6.435699
297	Fluorine	Air	mg	398.13195	40.09383	50.7769
298	Fluosilicic acid	Air	mg	8.268021	0.995208	1.199206
299	Formaldehyde	Air	g	11.03676	2.300738	2.515946
300	Formamide	Air	µg	44.925702	0.242316	0.248205
301	Formic acid	Air	mg	3.6181525	1.097101	1.11465
302	Furan	Air	µg	965.45732	285.7913	290.5214
303	Heat, waste	Air	MWh	4.8269579	0.672733	0.796245
304	Helium	Air	mg	182.58604	19.19234	22.16593
305	Heptane	Air	mg	729.41094	84.95117	96.80666
306	Hexane	Air	g	2.7865226	0.349473	0.390609
307	Hydrocarbons, aliphatic, alkanes, cyclic	Air	mg	85.862549	51.69195	51.62179
308	Hydrocarbons, aliphatic, alkanes, unspecified	Air	g	133.82345	-1.08189	0.756765
309	Hydrocarbons, aliphatic, unsaturated	Air	g	1.6902091	0.208711	0.256576
310	Hydrocarbons, aromatic	Air	g	12.792401	1.905661	2.43628
311	Hydrocarbons, chlorinated	Air	g	33.316103	32.45435	33.17984
312	Hydrogen	Air	g	25.163778	21.30016	21.73314
313	Hydrogen-3, Tritium	Air	kBq	64.17743	8.802083	9.69226

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
314	Hydrogen chloride	Air	kg	1.5554598	0.781981	0.783885
315	Hydrogen fluoride	Air	g	11.094427	0.821586	1.061301
316	Hydrogen peroxide	Air	µg	247.02482	108.6318	109.6665
317	Hydrogen sulfide	Air	g	7.9323323	0.341109	0.756738
318	Iodine	Air	mg	241.98565	29.30313	33.28563
319	Iodine-129	Air	Bq	8.9326145	1.415173	1.593491
320	Iodine-131	Air	Bq	448.91483	71.19861	80.25105
321	Iodine-133	Air	Bq	5.4113712	0.296457	0.243212
322	Iodine-135	Air	Bq	11.715008	0.640178	0.524285
323	Iron	Air	g	9.5269166	0.668395	0.898032
324	Isocyanic acid	Air	g	4.9227686	4.917987	4.918125
325	Isoprene	Air	µg	44.799999	13.2618	13.48131
326	Isopropylamine	Air	µg	93.710999	0.001605	0.002193
327	Krypton-85	Air	kBq	3.5427096	0.562415	0.634142
328	Krypton-85m	Air	Bq	177.93919	24.64349	28.06095
329	Krypton-87	Air	Bq	69.999754	10.31805	11.69448
330	Krypton-88	Air	Bq	69.297745	9.945578	11.29438
331	Krypton-89	Air	Bq	17.966311	2.400204	2.74074
332	Lactic acid	Air	µg	26.714047	0.123782	0.126766
333	Lanthanum-140	Air	µBq	719.4279	92.73423	106.1969
334	Lead	Air	g	1.6851636	-0.05725	0.051761
335	Lead-210	Air	Bq	100.75383	7.600119	9.650175
336	m-Xylene	Air	mg	32.898711	5.676534	6.318843
337	Magnesium	Air	g	2.7755466	0.009533	0.151585
338	Manganese	Air	mg	547.95374	26.78405	35.05394
339	Manganese-54	Air	µBq	66.965616	8.631866	9.884994
340	Mercury	Air	mg	238.66191	-9.29306	7.695269
341	Methane, biogenic	Air	g	59.136524	89.10635	4.587928
342	Methane, bromo-, Halon 1001	Air	ng	4.9185012	0.26798	0.219147
343	Methane, bromochlorodifluoro-, Halon 1211	Air	mg	6.5527133	1.398351	1.518189
344	Methane, bromotrifluoro-, Halon 1301	Air	mg	2.0237037	0.230273	0.262892

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
345	Methane, chlorodifluoro-, HCFC-22	Air	mg	25.156605	5.228458	5.687274
346	Methane, dichloro-, HCC-30	Air	mg	7.4926652	1.908989	1.888311
347	Methane, dichlorodifluoro-, CFC-12	Air	mg	3.9855	0.013043	0.013624
348	Methane, dichlorofluoro-, HCFC-21	Air	ng	33.309959	13.07541	13.26984
349	Methane, fossil	Air	kg	2.7585624	0.389715	0.481119
350	Methane, monochloro-, R-40	Air	mg	10.935501	0.595772	0.492691
351	Methane, tetrachloro-, CFC-10	Air	mg	13.201339	6.564043	6.607211
352	Methane, tetrafluoro-, CFC-14	Air	mg	63.684605	7.666048	9.237245
353	Methane, trichlorofluoro-, CFC-11	Air	ng	54.076939	21.22722	21.54287
354	Methane, trifluoro-, HFC-23	Air	µg	10.598622	4.160356	4.222221
355	Methanesulfonic acid	Air	µg	30.761118	0.009652	0.011774
356	Methanol	Air	g	4.2768774	1.471837	1.538666
357	Methyl acetate	Air	µg	12.406735	0.000374	0.000459
358	Methyl acrylate	Air	µg	103.77706	45.74893	46.19701
359	Methyl borate	Air	µg	11.241226	0.049162	0.050369
360	Methyl ethyl ketone	Air	mg	164.85875	72.42184	73.14544
361	Methyl formate	Air	µg	12.28092	0.241487	0.244779
362	Methyl lactate	Air	µg	29.326295	0.135892	0.139168
363	Methylamine	Air	µg	88.86563	0.105384	0.107234
364	Molybdenum	Air	mg	27.68401	6.087472	3.251318
365	Monoethanolamine	Air	mg	178.37776	83.44825	2.046184
366	Nickel	Air	mg	989.45353	109.2958	133.3653
367	Niobium-95	Air	µBq	7.9494016	1.024678	1.173435
368	Nitrate	Air	mg	60.04059	7.962828	8.954978
369	Nitrobenzene	Air	µg	241.36016	0.746976	0.765477
370	Nitrogen oxides	Air	kg	2.2103285	0.214193	0.279342

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
371	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	g	444.29847	67.25512	81.06339
372	Noble gases, radioactive, unspecified	Air	kBq	85880.802	13601.58	15314.74
373	Ozone	Air	g	4.0143515	0.544413	0.583844
374	PAH, polycyclic aromatic hydrocarbons	Air	mg	222.59362	4.619091	15.66296
375	Particulates, < 2.5 um	Air	g	524.57948	3.638642	34.19637
376	Particulates, > 10 um	Air	kg	1.4082238	-0.02069	0.06221
377	Particulates, > 2.5 um, and < 10um	Air	g	792.05301	-27.109	28.89876
378	Pentane	Air	g	12.019438	1.633589	1.799968
379	Phenol	Air	g	6.248991	3.080565	3.081311
380	Phenol, 2,4-dichloro-	Air	µg	62.128941	0.016073	0.016677
381	Phenol, pentachloro-	Air	mg	2.4905765	0.389504	0.437674
382	Phosphine	Air	ng	79.062314	34.85372	35.19508
383	Phosphorus	Air	mg	161.12297	15.74859	19.76082
384	Platinum	Air	ng	147.15768	21.25571	23.63588
385	Plutonium-238	Air	µBq	1.2185533	0.193053	0.217378
386	Plutonium-alpha	Air	µBq	2.7933784	0.442548	0.498311
387	Polonium-210	Air	Bq	170.3157	12.83203	16.62399
388	Polychlorinated biphenyls	Air	mg	3.0970721	-0.24373	-0.00268
389	Potassium	Air	g	8.039107	1.195936	1.378547
390	Potassium-40	Air	Bq	37.869582	2.40407	2.808682
391	Propanal	Air	µg	488.16797	43.72543	45.06098
392	Propane	Air	g	12.147586	1.957567	2.216838
393	Propene	Air	g	4.2790539	1.875994	1.910134
394	Propionic acid	Air	mg	82.824273	17.50842	18.73149
395	Propylamine	Air	µg	14.210231	0.076736	0.078602
396	Propylene oxide	Air	mg	618.63793	427.2189	427.1283
397	Protactinium-234	Air	Bq	3.9290281	0.339398	0.3367
398	Radioactive species, other beta emitters	Air	Bq	41.75757	6.871985	6.519746

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
399	Radium-226	Air	Bq	74.329113	8.578051	9.799705
400	Radium-228	Air	Bq	32.340416	-0.19943	1.604968
401	Radon-220	Air	Bq	954.37119	96.34561	102.4996
402	Radon-222	Air	kBq	194197.75	27156.15	30033.88
403	Ruthenium-103	Air	µBq	1.7465356	0.225128	0.257811
404	Scandium	Air	mg	18.530276	2.446114	2.764856
405	Selenium	Air	mg	72.479371	7.464399	8.289315
406	Silicon	Air	g	11.352511	0.005823	0.585694
407	Silicon tetrafluoride	Air	µg	39.262524	3.087365	4.865282
408	Silver	Air	µg	791.1077	112.1775	124.0451
409	Silver-110	Air	µBq	17.309505	2.231194	2.555107
410	Sodium	Air	g	1.4890027	0.146084	0.185125
411	Sodium chlorate	Air	mg	62.649696	0.067363	0.072754
412	Sodium dichromate	Air	mg	3.4228221	0.203001	0.209256
413	Sodium formate	Air	mg	3.3503222	2.91663	2.919813
414	Sodium hydroxide	Air	µg	920.4523	405.077	408.8937
415	Strontium	Air	mg	167.15124	5.536104	12.86142
416	Styrene	Air	mg	8.8149897	0.41574	0.477268
417	Sulfate	Air	g	41.149098	6.494225	6.735419
418	Sulfur dioxide	Air	kg	3.1519846	0.346587	0.415477
419	Sulfur hexafluoride	Air	mg	72.664915	8.786472	9.293197
420	Sulfur trioxide	Air	mg	1.451867	0.006013	0.006163
421	Sulfuric acid	Air	µg	193.20504	84.84532	85.66307
422	t-Butyl methyl ether	Air	µg	869.15695	70.1874	96.38723
423	t-Butylamine	Air	µg	95.67204	0.007808	0.009792
424	Terpenes	Air	µg	423.58334	125.3981	127.474
425	Thallium	Air	µg	789.08835	-20.8769	31.71305
426	Thorium	Air	µg	996.92234	-49.7614	22.71421
427	Thorium-228	Air	Bq	6.6422317	0.344923	0.52062
428	Thorium-230	Air	Bq	8.5005552	0.898601	0.957806
429	Thorium-232	Air	Bq	7.6298099	0.570809	0.717181
430	Thorium-234	Air	Bq	3.9294672	0.339445	0.33675
431	Tin	Air	mg	126.45855	-7.00145	1.937896
432	Titanium	Air	mg	516.75562	38.42321	56.89461

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
433	Toluene	Air	g	2.8142183	0.317156	0.34829
434	Toluene, 2-chloro-	Air	µg	126.38039	0.223275	0.229185
435	Trimethylamine	Air	µg	25.377172	0.000668	0.000819
436	Tungsten	Air	mg	2.0094519	0.281002	0.310778
437	Uranium	Air	mg	1.1035322	-0.04847	0.03043
438	Uranium-234	Air	Bq	22.499318	2.656112	2.864724
439	Uranium-235	Air	mBq	829.12044	115.9442	128.2303
440	Uranium-238	Air	Bq	39.262739	3.836792	4.479001
441	Uranium alpha	Air	Bq	79.751767	11.16314	12.34792
442	Vanadium	Air	mg	978.64813	177.3262	198.172
443	Water	Air	kg	215.81415	-0.0011	0.003853
444	Xenon-131m	Air	Bq	322.71902	47.05081	53.3699
445	Xenon-133	Air	kBq	10.310621	1.48307	1.683924
446	Xenon-133m	Air	Bq	43.094278	6.703677	7.569108
447	Xenon-135	Air	kBq	4.224075	0.609121	0.691486
448	Xenon-135m	Air	kBq	2.4962722	0.357467	0.406013
449	Xenon-137	Air	Bq	49.250564	6.581419	7.515014
450	Xenon-138	Air	Bq	431.10883	59.236	67.49165
451	Xylene	Air	g	3.2779178	0.392014	0.439755
452	Zinc	Air	g	5.0791171	-0.16533	0.149493
453	Zinc-65	Air	µBq	334.37559	43.101	49.35817
454	Zirconium	Air	mg	3.3962148	-0.26635	-0.00276
455	Zirconium-95	Air	µBq	326.83944	42.12958	48.24573
456	1-Butanol	Water	µg	697.17004	262.8187	265.4454
457	1-Pentanol	Water	µg	58.954967	0.317979	0.325707
458	1-Pentene	Water	µg	44.551288	0.24029	0.24613
459	1-Propanol	Water	µg	114.91322	0.436352	0.449203
460	1,4-Butanediol	Water	µg	46.463182	0.346086	0.349971
461	2-Aminopropanol	Water	µg	58.481337	0.004379	0.004943
462	2-Butene, 2-methyl-	Water	ng	9.8820256	0.0533	0.054596
463	2-Methyl-1-propanol	Water	µg	312.99437	0.55746	0.571392
464	2-Propanol	Water	µg	518.85131	0.008884	0.01214
465	4-Methyl-2-pentanone	Water	µg	127.60805	6.952603	5.685656
466	Acenaphthene	Water	µg	20.810741	2.480698	2.817488

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
467	Acenaphthylene	Water	µg	1.3015074	0.155143	0.176206
468	Acetaldehyde	Water	mg	291.69731	193.6843	193.69
469	Acetic acid	Water	g	4.0465366	2.736624	2.737237
470	Acetone	Water	µg	475.02269	17.70052	14.86234
471	Acetonitrile	Water	µg	25.48983	0.007998	0.009757
472	Acetyl chloride	Water	µg	46.313142	0.249794	0.255866
473	Acidity, unspecified	Water	mg	263.39289	231.8128	236.6861
474	Acrylate	Water	µg	216.47831	95.43199	96.36666
475	Actinides, radioactive, unspecified	Water	Bq	14.509045	2.298634	2.588272
476	Aluminium	Water	kg	1.3930323	0.109642	0.142393
477	Ammonium, ion	Water	g	34.672832	3.397907	1.784563
478	Aniline	Water	µg	370.6473	1.340656	1.373476
479	Antimony	Water	g	2.1029666	0.872881	0.917993
480	Antimony-122	Water	mBq	4.9992951	0.644409	0.737961
481	Antimony-124	Water	Bq	2.3812746	0.372166	0.419442
482	Antimony-125	Water	Bq	2.1751282	0.340154	0.383273
483	AOX, Adsorbable Organic Halogen as Cl	Water	mg	20.44901	4.09182	4.402181
484	Arsenic	Water	g	4.1690726	0.234398	0.393419
485	Barite	Water	g	29.83031	5.402058	5.922719
486	Barium	Water	g	34.483695	2.789411	3.249215
487	Barium-140	Water	mBq	21.899564	2.822852	3.232659
488	Benzene	Water	g	14.245575	6.833484	6.843416
489	Benzene, 1,2-dichloro-	Water	mg	1.5553288	0.114084	0.115307
490	Benzene, chloro-	Water	mg	25.952232	2.343975	2.368677
491	Benzene, ethyl-	Water	mg	83.175184	9.729043	11.0002
492	Beryllium	Water	mg	831.43377	68.38738	92.96003
493	BOD5, Biological Oxygen Demand	Water	kg	1.6423341	0.289549	0.307721
494	Borate	Water	mg	7.4872401	0.02424	0.024848
495	Boron	Water	g	38.505792	2.415542	3.951684
496	Bromate	Water	g	1.0904486	0.477118	0.481491
497	Bromide	Water	g	1.0355273	0.001302	0.001335

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
498	Bromine	Water	g	11.648755	1.414106	1.444287
499	Butene	Water	mg	70.956183	0.087301	0.089967
500	Butyl acetate	Water	µg	784.35137	341.6454	345.0591
501	Butyrolactone	Water	µg	1.3273588	0.580451	0.5864
502	Cadmium	Water	g	1.1461328	0.053739	0.102723
503	Calcium	Water	kg	13.023674	1.881971	2.257504
504	Carbon disulfide	Water	mg	1.1496143	0.015157	0.015518
505	Carbonate	Water	g	21.142854	14.40343	14.56724
506	Carboxylic acids, unspecified	Water	g	14.599419	1.790469	2.026463
507	Cerium-141	Water	mBq	8.7558044	1.128623	1.29247
508	Cerium-144	Water	mBq	2.6655532	0.34359	0.39347
509	Cesium	Water	mg	3.3457778	0.398826	0.452972
510	Cesium-134	Water	Bq	1.9902367	0.316425	0.356087
511	Cesium-136	Water	mBq	1.5539843	0.200309	0.229388
512	Cesium-137	Water	kBq	1.6693586	0.264402	0.297723
513	Chloramine	Water	mg	1.2926954	0.004169	0.004274
514	Chlorate	Water	g	10.472205	5.706412	5.786161
515	Chloride	Water	kg	12.008379	3.5103	3.886471
516	Chlorinated solvents, unspecified	Water	g	38.625069	37.7505	38.59361
517	Chlorine	Water	mg	305.07879	28.62005	29.45292
518	Chloroacetic acid	Water	mg	23.772574	0.18225	0.21973
519	Chloroacetyl chloride	Water	µg	77.993952	0.005841	0.006593
520	Chloroform	Water	µg	78.756693	5.465666	5.521515
521	Chlorosulfonic acid	Water	µg	92.690913	0.029085	0.03548
522	Chromium	Water	mg	248.63313	15.81756	25.45066
523	Chromium-51	Water	Bq	2.6642308	0.376749	0.427926
524	Chromium VI	Water	g	37.336558	-1.58089	1.038021
525	Cobalt	Water	g	28.381666	-0.23302	1.43157
526	Cobalt-57	Water	mBq	49.329323	6.358547	7.281647
527	Cobalt-58	Water	Bq	19.41825	2.894818	3.274081
528	Cobalt-60	Water	Bq	15.270079	2.253504	2.550862

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
529	COD, Chemical Oxygen Demand	Water	kg	3.0671348	0.510568	0.512525
530	Copper	Water	g	47.127604	1.074235	1.740184
531	Cumene	Water	g	20.201009	9.949499	9.956652
532	Cyanide	Water	mg	533.59172	-13.8625	21.07749
533	Dichromate	Water	mg	12.663155	0.73776	0.760847
534	Diethylamine	Water	µg	180.19669	0.597329	0.612136
535	Dimethylamine	Water	µg	803.90871	0.316777	0.339236
536	Dipropylamine	Water	µg	81.845815	0.379246	0.388388
537	DOC, Dissolved Organic Carbon	Water	kg	1.1221634	0.242106	0.194126
538	Ethane, 1,2-dichloro-	Water	mg	6.8632178	3.372637	3.460403
539	Ethanol	Water	mg	14.891851	1.442821	1.449374
540	Ethene	Water	mg	112.76001	14.11959	16.73694
541	Ethene, chloro-	Water	mg	320.55621	313.2387	320.2365
542	Ethyl acetate	Water	µg	330.1003	135.076	135.0921
543	Ethylamine	Water	µg	563.723	0.287952	0.298261
544	Ethylene diamine	Water	µg	454.76314	6.035574	6.212697
545	Ethylene oxide	Water	µg	609.25116	165.3948	46.25224
546	Fluoride	Water	g	120.89582	15.24807	18.78021
547	Fluosilicic acid	Water	mg	14.882438	1.791374	2.15857
548	Formaldehyde	Water	g	1.3745267	0.530268	0.54064
549	Formamide	Water	µg	107.82321	0.581575	0.59571
550	Formic acid	Water	µg	31.299776	0.168821	0.172924
551	Formic acid, thallium(1+) salt	Water	mg	29.488146	0.002406	0.003018
552	Glutaraldehyde	Water	mg	3.682754	0.666921	0.7312
553	Heat, waste	Water	MJ	931.84472	118.9571	112.7218
554	Hydrocarbons, aliphatic, alkanes, unspecified	Water	mg	434.95112	51.84737	58.88639
555	Hydrocarbons, aliphatic, unsaturated	Water	mg	40.257748	4.786064	5.435827
556	Hydrocarbons, aromatic	Water	g	1.8120329	0.218696	0.248073
557	Hydrocarbons, unspecified	Water	g	14.00207	9.810772	9.963309
558	Hydrogen-3, Tritium	Water	kBq	3892.9371	609.4426	685.0897

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
559	Hydrogen peroxide	Water	mg	5.0231038	1.716082	1.732732
560	Hydrogen sulfide	Water	mg	873.63253	236.8908	104.5937
561	Hydroxide	Water	mg	7.2152361	3.036091	3.070359
562	Hypochlorite	Water	mg	250.65107	34.8252	38.53346
563	Iodide	Water	mg	423.2373	43.46785	49.52204
564	Iodine-131	Water	mBq	434.26145	67.22297	75.82428
565	Iodine-133	Water	mBq	13.74806	1.772124	2.029392
566	Iron	Water	kg	1.9640884	0.126706	0.184755
567	Iron-59	Water	mBq	3.7796358	0.487195	0.557923
568	Isopropylamine	Water	µg	224.90915	0.003851	0.005262
569	Lactic acid	Water	µg	64.113475	0.297079	0.30424
570	Lanthanum-140	Water	mBq	23.324845	3.006571	3.443049
571	Lead	Water	g	8.8232608	0.280464	0.321997
572	Lead-210	Water	Bq	326.16879	5.920881	6.755859
573	Lithium	Water	g	32.719609	1.782596	1.457762
574	m-Xylene	Water	mg	1.0145977	0.050863	0.041724
575	Magnesium	Water	kg	5.5089618	0.471576	0.637599
576	Manganese	Water	g	449.78992	37.46103	51.54508
577	Manganese-54	Water	Bq	1.1938774	0.178314	0.201639
578	Mercury	Water	mg	192.15097	14.82988	21.75796
579	Methane, dichloro-, HCC-30	Water	mg	53.3104	7.841496	8.736634
580	Methanol	Water	mg	254.88668	50.79145	55.51955
581	Methyl acetate	Water	µg	29.776141	0.000897	0.001101
582	Methyl acrylate	Water	mg	2.0273154	0.893719	0.902472
583	Methyl formate	Water	µg	4.9030641	0.096412	0.097726
584	Methylamine	Water	µg	213.27075	0.252917	0.257357
585	Molybdenum	Water	g	3.249367	0.280234	0.377416
586	Molybdenum-99	Water	mBq	8.0419064	1.036601	1.18709
587	Nickel	Water	g	119.62673	-1.18457	5.728264
588	Niobium-95	Water	mBq	183.06464	28.59535	32.21179
589	Nitrate	Water	g	729.33207	54.6873	62.33891
590	Nitrite	Water	g	1.6546005	0.079731	0.037256
591	Nitrobenzene	Water	µg	967.24858	2.993497	3.067642

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
592	Nitrogen	Water	g	6.6163305	1.165659	1.185079
593	Nitrogen, organic bound	Water	g	4.1309225	0.647539	0.499649
594	o-Xylene	Water	µg	671.6213	36.59265	29.92451
595	Oils, unspecified	Water	g	224.39606	26.11729	30.30177
596	PAH, polycyclic aromatic hydrocarbons	Water	mg	169.77646	-10.1568	2.077199
597	Phenol	Water	g	5.9877105	2.833828	2.840212
598	Phosphate	Water	kg	1.8489999	0.149332	0.209702
599	Phosphorus	Water	g	2.0813277	0.046816	0.061784
600	Polonium-210	Water	Bq	464.55551	6.082637	7.35811
601	Potassium	Water	kg	3.4134832	0.31094	0.414781
602	Potassium-40	Water	Bq	80.98055	5.446545	5.843173
603	Propanal	Water	µg	85.292088	0.460333	0.471522
604	Propene	Water	g	8.8648813	4.458278	4.460773
605	Propionic acid	Water	µg	279.55341	0.048319	0.051071
606	Propylamine	Water	µg	34.104877	0.184165	0.188642
607	Propylene oxide	Water	g	1.4885942	1.027994	1.027776
608	Protactinium-234	Water	Bq	27.095437	3.789024	4.19053
609	Radioactive species, alpha emitters	Water	mBq	242.34904	3.671617	5.694093
610	Radioactive species, Nuclides, unspecified	Water	kBq	8.9031298	1.389457	1.561135
611	Radium-224	Water	Bq	167.2889	19.9413	22.64861
612	Radium-226	Water	kBq	17.49958	2.394854	2.649433
613	Radium-228	Water	Bq	391.2818	42.97205	47.8237
614	Rubidium	Water	mg	33.457778	3.988259	4.529722
615	Ruthenium-103	Water	mBq	1.6969147	0.218732	0.250487
616	Scandium	Water	g	1.4128768	0.119332	0.158371
617	Selenium	Water	g	2.0391211	0.172854	0.237359
618	Silicon	Water	kg	23.941348	-0.13907	1.268197
619	Silver	Water	mg	134.11125	7.678488	9.244142
620	Silver-110	Water	Bq	14.249956	2.09307	2.370264
621	Sodium	Water	kg	7.6918086	1.233958	1.402278
622	Sodium-24	Water	mBq	60.847208	7.843202	8.981837

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
623	Sodium formate	Water	mg	8.0489447	7.007026	7.014672
624	Solids, inorganic	Water	g	526.24484	71.61587	84.35097
625	Strontium	Water	g	178.26622	16.68134	21.66505
626	Strontium-89	Water	mBq	258.22828	37.25579	42.2398
627	Strontium-90	Water	kBq	12.371958	1.966211	2.216758
628	Sulfate	Water	kg	43.914118	4.165517	5.428152
629	Sulfide	Water	mg	221.9036	4.083579	4.469755
630	Sulfite	Water	mg	705.70925	95.96452	105.7814
631	Sulfur	Water	g	2.8180102	0.085056	0.094165
632	Suspended solids, unspecified	Water	kg	2.9817818	0.485089	0.55963
633	t-Butyl methyl ether	Water	mg	6.8677699	0.84975	0.959653
634	t-Butylamine	Water	µg	229.61506	0.018738	0.0235
635	Technetium-99m	Water	mBq	186.16526	24.03878	27.52466
636	Tellurium-123m	Water	mBq	257.34203	40.77875	45.90413
637	Tellurium-132	Water	µBq	465.64227	60.02126	68.73483
638	Thallium	Water	mg	114.48325	6.812138	11.22204
639	Thorium-228	Water	Bq	672.58603	79.78014	90.61763
640	Thorium-230	Water	kBq	3.6969083	0.516976	0.571757
641	Thorium-232	Water	Bq	8.792876	0.987972	1.046797
642	Thorium-234	Water	Bq	27.100133	3.789535	4.191069
643	Tin	Water	g	2.2232633	0.170343	0.318242
644	Titanium	Water	g	62.121237	14.75688	16.19733
645	TOC, Total Organic Carbon	Water	kg	1.1231519	0.242636	0.194632
646	Toluene	Water	mg	469.37575	52.65074	58.89241
647	Toluene, 2-chloro-	Water	µg	198.1811	0.465925	0.477896
648	Tributyltin compounds	Water	mg	18.716203	-0.05196	1.03305
649	Triethylene glycol	Water	mg	73.24314	15.6424	16.98345
650	Trimethylamine	Water	µg	88.639573	0.001602	0.001965
651	Tungsten	Water	g	1.1477062	0.057482	0.104907
652	Uranium-234	Water	Bq	32.514526	4.54683	5.028637
653	Uranium-235	Water	Bq	53.648968	7.502269	8.297251
654	Uranium-238	Water	Bq	243.75848	14.13435	15.81419
655	Uranium alpha	Water	kBq	1.5608911	0.218287	0.241421

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
656	Urea	Water	µg	130.09597	0.529816	0.542865
657	Vanadium	Water	g	11.735271	-0.02399	0.659835
658	VOC, volatile organic compounds, unspecified origin	Water	g	1.2386898	0.14907	0.169026
659	Xylene	Water	mg	365.79774	42.14943	47.4349
660	Zinc	Water	g	103.21189	6.463892	9.902115
661	Zinc-65	Water	mBq	824.95049	106.3361	121.7734
662	Zirconium-95	Water	mBq	9.5531574	1.231402	1.41017
663	2,4-D	Soil	mg	18.275233	0.050545	0.051381
664	Abamectin	Soil	µg	123.44452	0	0
665	Acephate	Soil	mg	117.66684	0	0
666	Aclonifen	Soil	µg	152.70577	13.2271	16.40763
667	Alachlor	Soil	mg	201.52224	0	0
668	Aldicarb	Soil	mg	91.114086	0	0
669	Aldrin	Soil	µg	2.3542558	1.037196	1.047388
670	Aluminium	Soil	g	3.7390093	0.375647	0.424841
671	Antimony	Soil	mg	2.6106777	0.132777	0.132787
672	Arsenic	Soil	mg	3.7705434	0.205108	0.223717
673	Atrazine	Soil	mg	18.40744	0.000272	0.000275
674	Azoxystrobin	Soil	µg	940.52683	0	0
675	Barium	Soil	g	1.0985366	0.157396	0.175075
676	Benomyl	Soil	µg	1.0869942	0.321795	0.327122
677	Bentazone	Soil	µg	77.933969	6.750503	8.373695
678	Benzene, pentachloronitro-	Soil	mg	10.110064	0	0
679	Bifenthrin	Soil	µg	102.86848	0	0
680	Boron	Soil	mg	111.3357	8.337004	8.847813
681	Bromoxynil	Soil	µg	999.29886	0	0
682	Buprofezin	Soil	µg	470.25174	0	0
683	Cadmium	Soil	mg	3.2416326	0.075777	0.084129
684	Calcium	Soil	g	20.24998	1.896073	2.22343
685	Carbetamide	Soil	µg	234.08466	5.980215	6.639047
686	Carbofuran	Soil	mg	1.5364584	0.17642	0.179341

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
687	Carbon	Soil	g	19.228023	1.249442	1.369184
688	Carboxin	Soil	µg	44.085991	0	0
689	Carfentrazone-ethyl	Soil	mg	1.2344452	0	0
690	Chloride	Soil	g	288.33786	7.196295	6.385155
691	Chlorothalonil	Soil	mg	112.09295	3.540077	3.623221
692	Chlorpyrifos	Soil	mg	11.286089	0	0
693	Chromium	Soil	mg	81.980248	2.305272	2.615444
694	Chromium VI	Soil	mg	485.04026	28.2747	29.15954
695	Clethodim	Soil	µg	191.04397	0	0
696	Clomazone	Soil	µg	323.29844	0	0
697	Cobalt	Soil	mg	1.086107	0.049278	0.061151
698	Copper	Soil	mg	317.61334	19.52177	20.15623
699	Cyanazine	Soil	µg	911.14086	0	0
700	Cyclanilide	Soil	mg	8.4054439	0	0
701	Cyfluthrin	Soil	mg	75.88282	0	0
702	Cypermethrin	Soil	mg	5.9146645	0.025145	0.025574
703	Deltamethrin	Soil	µg	176.34513	0	0
704	Dicamba	Soil	µg	293.90661	0	0
705	Dicofol	Soil	mg	74.134062	0	0
706	Dicrotophos	Soil	mg	38.795929	0	0
707	Dimethipin	Soil	µg	587.8366	0	0
708	Dimethoate	Soil	µg	499.64357	0	0
709	Disodium acid methane arsenate	Soil	mg	2.1749721	0	0
710	Disulfoton	Soil	µg	881.7549	0	0
711	Diuron	Soil	mg	80.653377	0	0
712	Endosulfan	Soil	mg	4.4674295	0	0
713	Endothall	Soil	µg	117.56732	0	0
714	Esfenvalerate	Soil	µg	176.34513	0	0
715	Ethephon	Soil	mg	323.29844	0	0
716	Etridiazole	Soil	mg	2.1161416	0	0
717	Fenpiclonil	Soil	mg	4.4171567	0.139791	0.143173
718	Fenpropathrin	Soil	µg	470.25174	0	0
719	Fluometuron	Soil	mg	237.73139	0	0

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
720	Fluoride	Soil	mg	432.84531	34.62283	36.99084
721	Glyphosate	Soil	mg	919.48248	1.446727	1.962893
722	Heat, waste	Soil	MJ	107.73617	8.168573	3.96139
723	Imidacloprid	Soil	mg	73.590363	0	0
724	Indoxacarb	Soil	mg	1.410761	0	0
725	Iprodione	Soil	µg	235.1288	0	0
726	Iron	Soil	g	38.559062	2.689571	3.791104
727	Lactofen	Soil	µg	220.4358	0	0
728	Lambda-cyhalothrin	Soil	mg	1.9398257	0	0
729	Lead	Soil	mg	15.108522	0.944514	0.955175
730	Linuron	Soil	mg	3.6458783	0.102131	0.126636
731	Magnesium	Soil	g	3.0156244	0.321975	0.371272
732	Malathion	Soil	mg	274.79987	0	0
733	Mancozeb	Soil	mg	145.58565	4.59783	4.705818
734	Manganese	Soil	mg	692.62001	53.47174	67.91331
735	Mepiquat chloride	Soil	mg	17.987496	0	0
736	Mercury	Soil	µg	93.626496	3.349642	3.482584
737	Metalaxil	Soil	µg	822.98297	0	0
738	Metaldehyde	Soil	µg	96.196543	2.032394	2.177735
739	Methamidophos	Soil	µg	176.34513	0	0
740	Methomyl	Soil	µg	529.0354	0	0
741	Metolachlor	Soil	mg	47.894906	0.737573	0.914926
742	Metribuzin	Soil	mg	5.1261641	0.161893	0.165695
743	Molybdenum	Soil	µg	437.52647	15.0288	17.52906
744	Monocrotophos	Soil	mg	72.708608	0	0
745	Monosodium acid methanearsonate	Soil	mg	171.62849	0	0
746	Naled	Soil	mg	1.2932172	0	0
747	Napropamide	Soil	µg	170.19353	3.595766	3.852908
748	Nickel	Soil	mg	-8.5016209	0.525724	0.558796
749	Norflurazon	Soil	µg	499.64357	0	0
750	Oils, biogenic	Soil	mg	815.92419	76.0067	99.77797
751	Oils, unspecified	Soil	g	221.47176	27.23104	30.8224
752	Orbencarb	Soil	mg	27.681795	0.874236	0.894769

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
753	Oxamyl	Soil	mg	5.6430443	0	0
754	Paraquat	Soil	mg	29.096801	0	0
755	Parathion	Soil	mg	7.2891265	0	0
756	Pendimethalin	Soil	mg	85.822271	0	0
757	Permethrin	Soil	µg	102.86848	0	0
758	Phorate	Soil	mg	15.283635	0	0
759	Phosphorus	Soil	mg	394.2075	35.40921	43.55746
760	Piperonyl butoxide	Soil	mg	72.708608	0	0
761	Pirimicarb	Soil	µg	7.3720447	0.638553	0.792097
762	Potassium	Soil	g	2.3431569	0.219199	0.267057
763	Profenofos	Soil	mg	8.1115843	0	0
764	Prometryn	Soil	mg	254.54344	0	0
765	Propargite	Soil	mg	2.0720626	0	0
766	Pyriproxyfen	Soil	µg	73.476653	0	0
767	Pyrithiobac sodium salt	Soil	mg	5.6430443	0	0
768	Silicon	Soil	g	4.6969895	0.246241	0.304162
769	Sodium	Soil	g	171.58775	0.662214	0.731702
770	Spinosad	Soil	µg	764.15249	0	0
771	Strontium	Soil	mg	21.0852	3.110261	3.465602
772	Sulfur	Soil	g	2.6014061	0.229033	0.256535
773	Sulfuric acid	Soil	ng	118.59343	52.28056	52.7926
774	Tebufenozide	Soil	µg	220.4358	0	0
775	Tebutam	Soil	µg	403.27967	8.520297	9.129604
776	Teflubenzuron	Soil	µg	341.74427	10.79284	11.04632
777	Thiamethoxam	Soil	mg	2.0573696	0	0
778	Thidiazuron	Soil	mg	15.048313	0	0
779	Thifensulfuron-methyl	Soil	µg	293.90661	0	0
780	Thiram	Soil	µg	1.9284571	0.570903	0.580354
781	Tin	Soil	mg	6.5165565	0.292943	0.293345
782	Titanium	Soil	mg	40.743833	2.805549	3.704013
783	Tralomethrin	Soil	µg	176.34513	0	0
784	Tribufos	Soil	mg	111.09889	0	0
785	Trichlorfon	Soil	mg	72.708608	0	0
786	Trifluralin	Soil	mg	190.27713	0	0

No	Substance	Compartment	Unit	OEM Office System	Reman 1 Office System	Reman 2 Office System
787	Vanadium	Soil	mg	1.1662181	0.080304	0.106021
788	Zinc	Soil	mg	262.51924	28.53734	26.79166

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10. Appendix D: Uncertainty Results

Table 27: Reman office system (A) and OEM office System (B) Uncertainty

Impact category	A >= B	Mean	Median	SD	CV (Coefficient of Variation)	2.50%	97.50 %	Std.err.of mean
Agricultural land occupation	0%	-76.4	-74.1	16.7	-21.80%	-110	-52.8	-0.00691
Climate change	0%	-922	-918	62.9	-6.83%	-1.06E+03	-806	-0.00216
Fossil depletion	0%	-282	-280	26.5	-9.40%	-335	-237	-0.00297
Freshwater ecotoxicity	0%	-22.1	-20.3	8.37	-37.90%	-44.3	-11.8	-0.012
Freshwater eutrophication	0%	-0.515	-0.46	0.264	-51.40%	-1.14	-0.222	-0.0163
Human toxicity	0%	-566	-504	261	-46%	-1.24E+03	-280	-0.0145
Ionising radiation	0%	-223	-163	186	-83.40%	-762	-60.4	-0.0264
Marine ecotoxicity	0%	-21.8	-20.2	7.99	-36.60%	-43.8	-12	-0.0116
Marine eutrophication	0%	-0.257	-0.256	0.021	-8.19%	-0.3	-0.217	-0.00259
Metal depletion	0%	-804	-803	53.2	-6.61%	-918	-708	-0.00209
Natural land transformation	16.20%	-0.178	-0.177	0.188	-106%	-0.555	0.184	-0.0334
Ozone depletion	0%	-7.04E-05	-6.88E-05	1.30E-05	-18.50%	-0.0001	-5.03E-05	-0.00584
Particulate matter formation	0%	-2.22	-2.18	0.282	-12.70%	-2.9	-1.78	-0.00402
Photochemical oxidant formation	0%	-2.72	-2.68	0.28	-10.30%	-3.36	-2.29	-0.00326
Terrestrial acidification	0%	-3.51	-3.48	0.302	-8.59%	-4.14	-3	-0.00271
Terrestrial ecotoxicity	0%	-0.186	-0.18	0.0302	-16.20%	-0.264	-0.143	-0.00513
Urban land occupation	0%	-11.5	-11	2.96	-25.80%	-19.1	-7.41	-0.00815
Water depletion	0%	-17	-16.9	1.77	-10.40%	-21	-14.1	-0.00329

11. Critical Review Committee Approval

November 29, 2016

Panel review of *Life Cycle Assessment Results: Comparison of a remanufactured Steelcase Avenir® office system at Davies Office, Inc. to an OEM office system*

Reviews of "**Life Cycle Assessment Results: Comparison of a remanufactured Steelcase Avenir® office system at Davies Office, Inc. to an OEM office system"** have been carried out by a panel of three life cycle assessment professionals. The panel has concluded that the study conforms to ISO 14044:2006 LCA standards for a full LCA to be published with comparative assertions.

This document summarizes the members of the peer review panel, panel review process, and panel comments with practitioner responses for three versions of the report. The final version, titled "Life Cycle Assessment Results: Comparison of a remanufactured Steelcase Avenir® office system at Davies Office, Inc. to an OEM office system" and dated November 17, 2016 is ISO compliant; previous versions are not, as indicated in this summary.

In this document, Panel Comments are in blue, the Practitioner Responses are in red, and final panel comments are in green. Oldest comments from the first version of the report are listed first (top of the cell) and comments listed on the Final Report listed last (bottom of the cell).

The panel chair has issued a letter of compliance to the LCA authors, to be included with this document in the LCA report.

Panel Review Process

Three versions of the LCA report were provided to the panel chair and distributed to panel members for review. In general, report reviews followed this process:

- Each panel member completed an independent review of the report and completed the attached checklist. Completed checklists and reports with comments in tracked changes mode were submitted to the panel chair and discussed via conference call to provide additional detail and come to a consensus.
- Panel comments are summarized in this document, with additional comments in the form of track changes on the report.
- The comments and suggestions in this document were forwarded to the LCA commissioner. The reporting format follows the list of ISO 14044 requirements for comparative studies.
- A "YES" indicates that either the required element was addressed adequately or was not applicable. A "YES, however" indicates that the required element was addressed, and can be strengthened by an edit or addition to the report. A "NO" indicates that the requirement was not adequately addressed and comments are provided, including a description of the problem and recommendations for revisions.

The three versions of the reports reviewed include:

- Life Cycle Analysis Results: Davies Results, file dated August 8, 2016
- Life Cycle Analysis Results: Davies Results", file dated October 7, 2016, and a copy of this document with the *Practitioner Response*

- Life Cycle Assessment Results: Comparison of a remanufactured Steelcase Avenir® office system at Davies Office, Inc. to an OEM office system." dated November 17, 2016, and a copy of this document with the *Practitioner Response*

Panel chair:
Kate Winnebeck, LCACP, New York State Pollution Prevention Institute, Rochester Institute of Technology

Contributing members of the panel:
Dr. Anahita Williamson
Thaddeus Owen, Sr. Engineer, Sustainability, Herman Miller and Owner OTEC LLC
Roy Green, HBF & Gunlocke

Panel Review Results

Are the methods used to carry out the LCA consistent with ISO 14044?

- Panel: No. Please see the Comments/Recommendations column in this document as well as the summary section at the end for specific comments.
- Panel: requirement met

Reporting	Met?
a) General Aspects	
1) LCA commissioner, practitioner of LCA (internal or external); Panel: Recommend actual practitioner's name(s) who performed the work should be listed. Practitioner response: Added practitioner bio in section 1.3 LCA Practitioner Panel: requirement met	YES, however
2) Date of report; Panel: Put the date on the front page of the report. Practitioner response: Added date to front page and is current date of revisions Panel: requirement met	NO
3) Statement that the study has been conducted according to the requirements of this International Standard.	YES
b) Goal of the Study	
1) Reasons for carrying out the study; Panel: A discussion of why this study is important and how it can add value to the industry sector would be helpful. See the report for specific comment & location within the report. Practitioner response: Added reference and language to section 2.2 regarding importance. Panel: requirement met	YES, however
2) Its intended applications;	YES
3) The target audiences;	YES
4) Statement as to whether the study intends to support comparative assertions intended to be disclosed to the public	NO

Reporting	Met?
Panel: This does not appear in the Goal section of the study – update language in the goal to add "in the form of a comparative assertion" or similar language Practitioner response: Updated language in section 2.2 Panel response: Page 17 says "This life cycle assessment report is intended for public dissemination, subject to the terms and conditions discussed in the Disclaimer section. Page 20 says "this assessment may be disclosed to the public…". For consistency, this language should be made clear. Practitioner response: Page 17 and page 20 updated to read as follows for consistency: "This life cycle assessment is intended for public dissemination, and may be disclosed to the public subject to the terms and conditions set forth in the Acknowledgements and Disclaimers section" Panel: requirement met	
c) Scope of the Study	
1) Function, including Panel: Clearly laying out all the scenarios being modeled in the LCA would be helpful. Practitioner response: Added description in section 2.3.2 Panel: requirement met	YES, however
i) Statement of performance characteristics;	YES
ii) Any omission of additional functions in comparisons. Panel: Clarify if comparison is OEM Avenir to Davies Avenir, and if any components (such as task lights) are omitted from either scenario. See the report for specific comments and locations within the report. Practitioner response: Added clarification in section 2.3.2. This is a comparison between Davies Reman Avenir and OEM Avenir. Electrical, communication and lighting are omitted from study. Panel: requirement met	NO
2) Functional unit, including	YES
i) Consistency with goal and scope;	YES
ii) Definition;	YES
iii) Result of performance measurement. Panel: Need to justify 10 year lifespan portion of functional unit. BIFMA PCR states that BIFMA X5.5 & 5.6 testing determines the product lifetime and if no such testing has been performed, Warranty alone is not enough to justify service life. Practitioner response: Added comment and reference in section 2.3.2. Davies indicated that furniture is typically in service over 10 years and only gets retired due to the changing needs of their customers and not due to any failure of the furniture. Panel response: Consider adding the vintage of the Steelcase products remanufactured in cycle 1 and the remanufacture cycle 2 timing (between cycle 1 and 2) to further justify the 10 year time period. It is not clear from the report how long of a time passes between reman cycles. Practitioner response: Davies does not track age of the components being remanufactured, the vintage of the components in this study can be assumed to be from the early 2000's (2000 – 2004) based on the manuals referenced. The 10 year life span is subjective on a case by case basis and influenced by changing trends, styles, company expansion or downsizing, along with functional	NO

Reporting	Met?
requirements. The time between first and second remanufacturing cycle is assumed to be similar since the performance of the reman office is the same if not better than OEM. Panel: requirement met	
3) System boundary Panel: Met requirement for remanufacturing only; not for the OEM. Need to include information on process flow & system boundaries for OEM. See comments in the report. Reman product receives credit for using OEM product and also credit for recycling at EOL – this is double accounting. Reman should not be taking credit at EOL, per the PCR. Practitioner response: Section 2.3.3, added OEM process flow and boundary. Process flow from OEM Answer in Dietz study and processes and materials not in Avenir are indicated, the remaining processes are assumed representative of the Avenir. The impacts are averaged over the number of lifecycles for the product. Panel response: This statement needs to be clarified. Practitioner response: Impacts are aggregated from each life cycle the product experiences and is divided by the number of life cycles. (L1+L2+L3)/3 Practitioner response: Added clarification in section 2.4 Methodology Panel response: Appears that double counting still occurs – taking credit and subtracting burden for recycling scrap manufacturing materials. The materials should be recycled with 0 net impact/benefit. Practitioner response: The recycling of steel has been removed from the independent life cycle comparison between OEM and Reman. The impact resulted in the Reman 1 and Reman 2 cycle being similar. Reman 1 has additional energy requirements for component sizing, while reman 2 has increased replacement rates for materials. The differences balance the two life cycles so that their impacts appear equivalent. Panel: requirement met	NO
i) Omissions of life cycle stages, processes or data needs; Panel: Need to very clearly disclose that Reman is not accounting for all OEM stages, either in limitations or omissions section of the report. Practitioner response: Added a paragraph in section 2.3.4 boundary exclusions Panel: requirement met	NO
ii) Quantification of energy and material inputs and outputs; and Panel: Data for OEM is not clear. Inputs and outputs need to be well defined. Practitioner response: Updated in report for system boundary 2.3.3 Panel: requirement met	NO
iii) Assumptions about electricity production. Panel: These are not addressed. Electricity for the OEM should likely be Mexico production vs US (or NY) based for Davies. OEM data is from 2006; Steelcase is likely to be more energy efficient now. It is unclear how grid energy was modeled and how MJ for manufacturing of OEM was calculated. Also not clear where the data came from. Practitioner response: Section 3.1.2 describes how OEM energy is derived. MJ for OEM manufacturing was derived from Dietz 2005, The study provides rates for welding and powder coating which are applied to Ecoinvent processes in simapro, Panel: requirement met	NO
4) Cut-off criteria for initial inclusion of inputs and output, including Panel: Need to discuss whether cut off or avoided burden model is used to model recycling and how this may impact the results.	YES, however

Reporting	Met?
Practitioner response: Avoided burden is used to model recycling. Updated in report Panel: requirement met	
i) Description of cut-off criteria and assumptions; Panel: Criteria is provided for mass only. Provide criteria for energy, per the BIFMA PCR (it is unclear if the PCR is followed in its entirety throughout the analysis or only the functional unit section). Discuss assumptions. Practitioner response: More PCR definition regarding how it is followed was added to section 2.1 and indicates what was followed and what was not. Energy added to cutoff in section 2.3.5 Panel response: While assumptions are addressed throughout the report, many are missing from the summary table in section 3.2. We suggest adding them, so that all study assumptions are in one place. Assumptions include: a. It is assumed that since the Answer and Avenir® both have similar component composition that the production process for the Answer will also be similar to the Avenir®. b. Use phase of both Davies and the OEM fall within the boundary, however it is assumed that both office systems will experience similar use and impacts therefore this phase of the life cycle is ignored. c. The second remanufacturing life cycle is slightly higher compared to the first due to the fact that components are assumed to not be resized in the second life cycle. d. The current model assumes only the steel material in the panel frame and file storage go to recycling, all other materials are sent to landfill. e. The individual component process flows were adopted from (Dietz 2005) study and is assumed that these processes are representative of the Avenir® process flow. Portions of the Steelcase Answer process flows may vary from Avenir® based on the Avenir® material content. f. The lateral file process flow illustrated in Figure 12 for the Steelcase Answer. It can be assumed that this is representative of the Avenir® process. Eliminated from the evaluation are the plastic materials and electroplating. g. The Steelcase Answer panel process flow illustrated in Figure 13 is assumed to be representative of the Avenir® process, excluding the specific components highlighted. The electrical and plastic components were excluded along with the aluminum slatwall which were not observed in the Avenir®. h. The Steelcase Answer Work Surface process flow illustrated in Figure 14 is assumed to be representative of the Avenir® process flow, excluding the highlighted materials and processes. i. Material and process models for OEM packaging are derived from (Dietz 2005) analysis of Steelcase Answer office products, which are assumed to share the same packaging with the Steelcase Avenir® system. j. This study assumes that 100% of the steel contained within the panel and file/pedestal storage will be recycled. The remaining panel materials are sent to landfill. 100% of the work surface is assumed to go through the MSW waste stream. Practitioner response: The practitioners appreciate the review team response and thorough description of assumptions above. The practitioners have taken these recommendations and applied to the assumptions section of the report. Panel: requirement met	NO
ii) Effect of selection on results; and Panel: Discuss more thoroughly in the report. See comments in report. Practitioner response: Addressed in report. Panel: requirement met	NO

Reporting	Met?
iii) Inclusion of mass, energy and environmental cut-off criteria Panel: Same comment as 4i. Environmental cut offs are not discussed. Practitioner response: More PCR definition regarding how it is followed was added to section 2.1 and indicates what was followed and what was not. Energy added to cutoff in section 2.3.5 No environmental cutoff is applied Panel: requirement met	NO
d) Life Cycle Inventory Analysis	
1) Data collection procedures; Panel: See specific comments in report. Practitioner response: Addressed in report, comments replied to. Panel: requirement met	YES, however
2) Qualitative and quantitative description of unit processes;	YES
3) Sources of published literature; Panel: See specific comments in the report where references are needed. Practitioner response: Updated references in report where there were specific comments Panel: requirement met	YES, however
4) Calculation procedures; Panel: Add more detail; see comments in report. Practitioner response: Updated in report, comments addressed Panel: requirement met	YES, however
5) Validation of data, including i) Data quality assessment; ii) Treatment of missing data; Panel: This section is missing; please include a section that specifically addresses data quality. Data validation was performed for the primary data but not for any of the secondary data. Missing data was not listed nor discussed. Need to list version of ecoinvent dataset that was used. Need more clarity on OEM datasets; where did they come from and are they representative of the systems studied? Practitioner response: Section 3.4 discusses data quality. See updates in subsections. Panel: requirement met	NO
6) Sensitivity analysis for refining the system boundary; Panel: Sensitivity needs to be run against the OEM system being compared, such as energy production in another country and lower OEM energy use during manufacturing due to efficiencies gained in the last 10 years. Please at least mention this (sensitivity) under 2.3.4 'Boundary Exclusions' Practitioner response: Sensitivity added for additional energy mix by region. Used Mexico and Michigan as OEM scenarios while using NY for reman. Panel: requirement met	NO
7) Allocation principles and procedures i) Documentation and justification of allocation procedures; and ii) Uniform application of allocation procedures.	NO

Reporting	Met?
Panel: OEM allocation is not clear. Please update Section 2.3.7 of the report as it is unclear and difficult to follow. Practitioner response: Section updated Panel: requirement met	
e) Life Cycle Impact Assessment, where applicable:	
1) The LCIA procedures, calculations and results of the study; Panel: It is unclear if the results from the 2005 study were used to model Reman or if the data from the study was used to build a model in SimaPro to get the results. See additional comments in the report. Practitioner response: Energy, process and material data were used from the 2005 study. The OEM model was built in Simapro based on measurements of the OEM core collected at Davies prior to remanufacturing. The energy and process data from the 2005 LCA was then implemented in the model for the OEM along with any material composition data. Report has been updated to clarify Panel: requirement met	NO
2) Limitations of the LCIA results relative to the defined goal and scope of the LCA; Panel: The goal and scope contain language about comparison of OEM to Davies systems; the limitations section does not address LCIA limitations that address this goal. It is unclear how OEM data was modeled (see comment under e1 above), making it difficult to evaluate whether or not the limitations are well addressed. See additional comments in report. Practitioner response: Updated in report section 4.3 along with updates from in e1 above Panel: requirement met	NO
3) The relationship of LCIA results to the defined goal and scope, see 4.2;	YES
4) The relationship of the LCIA results to the LCI results, see 4.4;	YES
5) Impact categories and category indicators considered, including a rationale for their selection and a reference to their source;	YES
6) Descriptions of or reference to all characterization models, characterization factors and methods used, including all assumptions and limitations;	YES
7) Descriptions of or reference to all value-choices used in relation to impact categories, characterization models, characterization factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence on the results, conclusions and recommendations; and	YES
8) A statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks and, when included as a part of the LCA Panel: Report states "Recipe v1.11 (2014) impact assessment method chosen which links 18 midpoint impact categories to 3 damage categories (end points)." However, a statement that "the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risk…" should be added to the limitation section. Practitioner response: Added to limitations section 2.3.6 Panel: requirement met	NO
ii) A statement and justification of any grouping of the impact categories; Panel: Does not appear grouping was performed	Not applicable
iii) Any further procedures that transform the indicator results and a justification of the selected references, weighting factors, etc.; Panel: Does not appear weighting was used	Not applicable

Reporting	Met?
iv) Any analysis of the indicator results, for example sensitivity and uncertainty analysis or the use of environmental data, including any implication for the results; Panel: Sensitivity needs to be run against the OEM system being compared, such as energy production in another country and lower OEM energy use during manufacturing due to efficiencies gained in the last 10 years. Clarify why uncertainty analysis was not performed. Practitioner response: Sensitivity evaluated for energy in Mexico, Michigan for OEM vs NY for reman. Uncertainty analysis added. Panel: requirement met	NO
v) Data and indicator results reached prior to any normalization, grouping or weighting shall be made available together with the normalized, grouped or weighted results. Panel: Does not appear that weighting or grouping were performed.	Not applicable
f) Life Cycle Interpretation	
1) The results; Panel: While the results provided are clear and Davies results are understandable, it is not clear how the OEM results are calculated as the data source is not clear. See summary comments at end of this document. Practitioner response: OEM is calculated in the same manner as Davies with ReCiPe. OEM process and energy information are derived from the OEM LCA conducted at the University of Michigan (Dietz 2005) Report has been updated Panel: requirement met	YES, however
2) Assumptions and limitations associated with the interpretation of results, both methodology and data related; Panel: A discussion of assumptions and limitations of results, in terms of both methodology and data choices is not included. There appear to be limitations in that the OEM data is old and no longer uses the same manufacturing plant and thus may not be comparable to 2015 Davies manufacturing energy. Furthermore, the data assumptions and limitations that were made – and therefore impact the results – are not adequately discussed. Practitioner response: Expanded on OEM limitations and data source in report. Panel: requirement met	NO
3) Data quality assessment;	YES
4) Full transparency in terms of value-choices, rationales and expert judgments.	YES
g) Critical Review, where applicable	
1) Name and affiliation of reviewers; 2) Critical review reports; 3) Responses to recommendations.	YES
Further Reporting Requirements for Comparative Assertion Intended to be Disclosed to the Public	
a) Analysis of material and energy flows to justify their inclusion or exclusion;	YES
b) Assessment of the precision, completeness and representativeness of data used;	NO

Reporting	Met?
Panel: These assessments were performed for the Davies primary data and are missing for the OEM data and secondary data used in both the OEM and Davies life cycles. Practitioner response: Added to the report. Panel: requirement met	
c) Description of the equivalence of the systems being compared in accordance with 4.2.3.7; Panel: The study should very clearly lay out the two systems, OEM system studied, and the Davies System outlining the age of the data, the System name (Davies compared Avenir refurbished product to Answer product), components of each system and prove the equivalence of the systems being compared. Other potential equivalence issues include 2005 Steelcase data vs. 2015 Davies data, Grand Rapids manufacturing of OEM vs Mexico Manufacturing, and any efficiencies that may have been gained in 10 years at OEM. Practitioner response: 2005 was a study conducted for. The materials in Davies and OEM are exactly the same in this model, the only difference is the manufacturing energy and material usage. It is stated in the report that the study compares OEM Avenir (based on data from LCA for Answer) with Avenir reman. Panel: requirement met	NO
d) Description of the critical review process;	YES
e) An evaluation of the completeness of the LCIA;	YES
f) A statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use; Panel: This information is provided for ReCiPe and is missing for CED. See section 4.1.2 of the report. Practitioner response: Added reference and additional discussion in the text relating to acceptance and reasoning for use in this study. Panel: requirement met	NO
g) An explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study; Panel: The report is missing the reasoning for the indicators the LCA team chose to focus on, such as climate change. It is unclear why this indicator was chosen and not others. See the report for additional comments. Practitioner response: Explanation added in report: the normalized ratio of impacts between OEM and reman are similar for most categories. Additional discussion for any deviation added, along with charts for all categories compared. Panel: requirement met	NO
h) The results of the uncertainty and sensitivity analyses; Panel: See comment under header e.8.iv. of this document. Practitioner response: Uncertainty analysis added, additional sensitivity conducted, report updated. Panel: requirement met	NO
i) Evaluation of the significance of the differences found. Panel: A summary or conclusion section is missing from the report. This is where the significant differences between the OEM and Davies system should be summarized, leaving the reader with a clear understanding of the high level results. Practitioner response: Conclusion section added Panel: requirement met	NO
If grouping is included in the LCA, add the following:	
a) The procedures and results used for grouping;	Not applicable

Reporting	Met?
Panel: Grouping was not part of the study	
b) A statement that conclusions and recommendations derived from grouping are based on value-choices; Panel: It does not appear this is needed as grouping was part of the study	Not applicable
c) A justification of the criteria used for normalization and grouping (these can be personal, organizational or national value-choices); Panel: It does not appear weighting or normalization were performed	Not applicable
d) The statement that "ISO 14044 does not specify any specific methodology or support the underlying value choices used to group the impact categories";	Not applicable
e) The statement that "The value-choices and judgments within the grouping procedures are the sole responsibilities of the commissioner of the study (e.g. government, community, organization, etc.)".	Not applicable

Are the methods used to carry out the LCA scientifically and technically valid?

- Panel: The methods used to carry out the Davies portion of the LCA are scientifically and technically valid. It's unclear what methods were used to carry out the OEM assessment.
  - Practitioner response: Same method used for OEM
  - Panel response: please elaborate and give details here explaining the methods for the OEM assessment
  - Material mass of the components was obtained from the OEM cores collected at Davies. Other material composition and process data for the OEM were derived from the Dietz 2005 study. Since the components in the Dietz 2005 study are similar to the Avenir remanufactured by Davies it was assumed that the processes are the same. Raw data from the Dietz 2005 study was also used and an OEM model was built in Simapro. The OEM model was then run using the ReCiPe Midpoint impact method for comparison to the reman.
- Panel: requirement met

Are the data used appropriate and reasonable in relation to the goal of the study?

- Panel: It is questionable whether, with the large contribution of manufacturing energy and the direct comparison of manufacturing energy from the OEM to the Davies product that 2005 manufacturing energy taken from the OEM LCA should be compared to 2015 Davies energy use, especially assuming the OEM has made energy reduction or efficiency progress, which may be able to be determined from BIFMA level results, and the fact that Manufacturing of the OEM product likely no longer occurs in Grand Rapids, MI.
  - Practitioner response: It can be assumed that the Avenir cores were produced 10 years prior to this assessment or more and therefore would have the embodied energy from that time. Because the study combines the burden for each life cycle and averages based on the number of life cycles, the overall magnitude of the impacts for each life cycle may vary, however the relative impact reduction from life cycle to life cycle should be similar.

- Panel: It is unclear exactly what data was used for the OEM system – was it from the 2005 or 2006 Steelcase LCA? Were the Steelcase LCA results used or was LCI data pulled, remodeled, and run with Recipe 2014? It is critical that this is well documented.
  - Practitioner response: Data used from Dietz 2005 Thesis at University of Michigan for Steelcase Answer office products. Raw data was extracted and re run in simapro for the OEM model built. Energy material and process information from the OEM study was used to build the model in simapro.

- Panel: requirement met

Do the interpretations reflect the limitations identified and the goal of the study?

- Panel: The interpretations that the Davies process is less impactful overall is likely not in question, however, the amount by which it is less impactful is questionable due to the dated nature of the OEM manufacturing data and the likelihood that the OEM has moved operations out of Michigan. Without sensitivity analyses, this conclusion cannot be drawn.
    - Practitioner response: Sensitivity has been conducted and included in the report for variation of energy mix by location.
    - Panel response: elaborate and detail the sensitivity analyses here, the results, and how the results affect the broader LCA results
    - Practitioner response: The sensitivity analysis for energy mix comparison used one representative product, which was a 65 x 48 inch panel that is not indexed during the remanufacturing cycles. Each cycle starts with the OEM and ends with end of life disposition previously defined in this report. This sensitivity used the US average as the baseline, where the assumption is both the OEM and Davies use that energy mix. The other scenarios varied the OEM between the Mexico and Michigan energy mixes while Davies used the New York mix for both. The sensitivity was modeled using both the ReCiPe midpoint and CED methods. The results indicate that the energy mix does not have a significant impact in the life cycles. This can be attributed to the fact that other contributors outweigh the production energy impacts, such as material production.

- Panel: Limitations of the study are not well described. This section of the report needs to be enhanced and should include sensitivity analyses. See the comments in the chart above and within the LCA report.
    - Practitioner response: Limitations updated and additional sensitivity performed.
    - Panel response: compile a summary of the limitations to include in this section of the report. All of the limitations exist in the report, but are not found in this section.
    - Practitioner response: The lack of current primary OEM Steelcase Avenir® data is one limitation that is important to note. The OEM Steelcase LCA referenced in this study is approximately 11 years old at the time of this report, therefore current conditions and practices for the OEM may result in impacts that are greater or less than reported in the OEM study. This can be attributed to improved process efficiencies, change in manufacturing location, or change in materials used.

Limitation ID	Limitation Description
1	OEM Avenir® production data not readily available, production data for Steelcase Answer office products used from (Dietz 2005) Study
2	OEM process and manufacturing data approximately 11 years old, improvements in efficiency, and changes in manufacturing location may result in variation of the impacts
3	Current OEM packaging materials and practices are unknown

Limitation ID	Limitation Description
4	Production energy mix may be different due to changes in manufacturing location

- Panel: It is unclear if the BIFMA PCR was used consistently, or if only the functional unit portion of the PCR was used. There are discrepancies in the BIFMA PCR methodology and the methodology presented in this report.
  - Practitioner response: The BIFMA PCR was not used in its entirety. Explanation was added to the report to clarify what portions were used explicitly and what portions were used as a guide or reference only.
- Panel: It is unclear whether the LCA report will be publically available. The current language says that it "may be available." Please clarify the intention.
  - Practitioner response: The intent is for this report to be made public. This project was funded in part by the Center of Excellence in Advanced & Sustainable Manufacturing (COE-ASM). There is a disclaimer in the report regarding how this report should be used and if it is made public should be used in its entirety as per the terms and conditions of the COE-ASM, and any abbreviated publications have to be agreed upon by both parties.
- Panel: requirement met

Is the study report transparent and consistent?

- Panel: It should be made more clear the limitation of the OEM data and that comparison to this data, while not exact, is likely directionally appropriate. It seems obvious that the Davies process will be less impactful than the OEM and that refurbishing furniture is preferable to recycling or landfilling.
  - Practitioner response: Limitations described in section 4.3 updated. Further clarification made throughout the report where reviewers had comments.
  - Panel response: compile a summary of the limitations to include in this section of the report. All of the limitations exist in the report, but are not found in this section.
  - Practitioner response: Summary table added in section 2.3.6 see response above for Limitations and table.
- Panel: The source of OEM data is not transparent – it's unclear which Steelcase study was used as the data source, what data was used from the study (ie. results or LCI data), and how LCIA data was determined (ie. results from the report or LCI data modeled and run with Recipe 2014).
  - Practitioner response:
    - OEM Data derived from *Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005*
    - Raw data from that study was used to build the OEM Model and run using the current ReCiPe 2014 method.
    - OEM mass measurements and material quantities were collected directly at Davies from the OEM Avenir Cores, prior to remanufacturing. Clarification has been made in the report.
- Panel: requirement met

Conclusion

- Panel: The study should include more detail in the limitations section and more clearly address the data limitations, as well as be clearer as to how the OEM data was used in order to clearly meet the ISO requirements. It should be made clearer the case for comparison of older OEM data to current Davies data.
    - Practitioner response: Conclusion added
    - Panel response: the practitioner comment doesn't address the whole of the panel's comments – detail the limitations section changes, data limitation section, and comparison of older OEM data to current Davies data.
    - Practitioner response: See responses above regarding limitations, and expansion to the Limitations section in the report. Also, the Conclusion section reiterates limitations of the study and provides guidance on how the results should be used and interpreted for this specific comparison and not broadly applied.
    - Panel: requirement met

- Panel: The study should very clearly lay out the two systems, OEM system studied, and the Davies system outlining the age of the data, the system name (appears that the study compared Avenir refurbished product to Answer OEM product), components of each system and prove the equivalence of the systems being compared.
    - Practitioner response: Additional explanation added in the report,
    - Panel response: add the explanation here
    - Practitioner response: The study compared the OEM Avenir® to the remanufactured Avenir®. The individual component process flows were adopted from (Dietz 2005) study and is assumed that these processes are representative of the Avenir® process flow. Portions of the Steelcase Answer process flows may vary from Avenir® based on the Avenir® material content. The Answer work surface had steel legs and a process for the production of these legs is included in the Answer process flow, while the Avenir ®does not have these support legs. Materials and processes contained within the Answer that were not found in the Avenir® were excluded. Material mass and product composition were collected at Davies from the Avenir® cores on hand prior to remanufacturing. The (Dietz 2005) study provided the process and additional material information for the OEM.
    - Panel: requirement met

The critical review panel would like to draw particular attention to the following findings that are of greatest concern:

- It is unclear whether the analysis is comparing the Davies remanufactured office system to the Steelcase OEM Answer or Avenir system. The reviewers struggled with the OEM system, specifically understanding exactly what is included in the system and where the data is from. Throughout the report, the OEM system is difficult to follow.
    - Practitioner response: The study is comparing the OEM Avenir to the Davies remanufactured Avenir®. The OEM study of the Answer used primary data to support building of the Avenir model since both are comprised of the same components and materials.
    - Panel: requirement met

- Furthermore, it is unclear whether the LCA team used (1) the results from the 2005 Steelcase LCA or (2) the data in the 2005 Steelcase LCA to build a model in SimaPro and obtained results using ReCiPe 2014. The results presented in the 2005 study are not only more than ten years old, but also use a different version of ReCiPe than the current study, making the comparison inaccurate. It is not clear if the systems scopes are equivalent and set at facility gate to facility gate or a larger scope. The limitations section needs to be expanded, as detailed in the chart in this document.

- Practitioner response: OEM from : (Dietz, B. A. (2005). *Life cycle assessment of office funiture products* (Doctoral dissertation). Data from the 2005 LCA was used to build a model in Simapro using Recipe 2014.
- Panel response: is this the correct study? Here a doctoral dissertation is cited; throughout the report, a Master's Thesis is cited. Please be consistent and ensure the correct study is cited.
- Practitioner response:
  - The correct study is the master's thesis; report references have been updated
  - Dietz, Bernhard A.; Life Cycle Assessment of Office Furniture Products; Master Thesis; The University of Michigan, School of Natural Resources and Environment; Ann Arbor, Michigan; April 2005
- Panel: requirement met

- The 2005 OEM manufacturing energy is compared to 2015 Davies manufacturing energy. This assumption that the two are comparable should be highlighted, discussed and justified.
  - Practitioner response: It can be assumed that the Avenir cores were produced 10 years prior to this assessment or more and therefore would have the embodied energy from that time. Because the study combines the burden for each life cycle and averages based on the number of life cycles, the overall magnitude of the impacts for each life cycle may vary, however the relative impact reduction from life cycle to life cycle should be similar.
  - Panel: requirement met

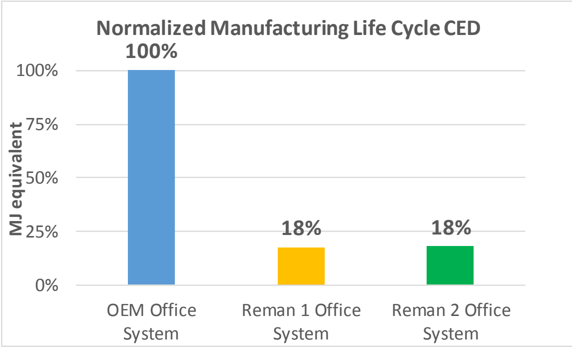
- Clarify how the BIFMA PCR was used to guide the LCA. The PCR was not used in its entirety as there are discrepancies in the PCR methodology and the methodology used in this study.
  - Practitioner response: Clarified in the report, section 2.1
  - Panel response: add clarification here
  - Practitioner response: The BIFMA PCR was not intended for a comparative assessment, and not designed with remanufacturing in mind. Therefore, it was only used as a general guide for this study and not followed explicitly. Table 1 was added to the report on pages 18 and 19, and is shown here.

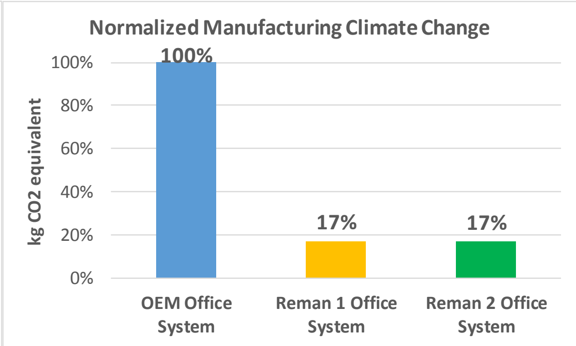
PCR Category	General Category Metric/Description	Followed in Study (Y/N/ or Guide only)
Goal and Scope	The scope of the LCA shall conform to the ISO 14040 series (ISO 14044 Section 4.2.3.1) and be from cradle-to-grave.	Yes
Product Description	• Category of the product • Number of users • Area of physical floor space • Photo Image of product(s) • The features that the reference product includes in the arrangement / configuration of the LCA study	Yes
Functional Unit	The functional unit shall be one square meter ($1m^2$) of workspace for a period of 10 years	Guide Only

System Boundary	• Material acquisition and processing • Production • Distribution, storage, use • End of Life	Guide Only
Allocation Rules	Where possible, allocation should be avoided by dividing unit processes into two or more sub-processes (as specified in ISO 14044, Section 4.3.4, Allocation	Yes
Sensitivity Analysis	• Sensitivity analyses shall be performed when allocation is used • If proxy data representing more than 1% of the mass or energy of the system is used, a sensitivity analysis shall be performed using a range from half to twice the reference flow of the unit process	Guide Only
LCIA Method	• TRACI 2.1	Guide Only

  - Panel: requirement met

- In the remanufactured product life cycle, Davies receives their materials burden free (ie. no environmental impact) and also disposes of them burden free at end of life. This is double counting and is not allowed per ISO. Davies can either (1) receive their materials burden free and take the environmental impact of disposal at end of life or (2) receive the OEM burden of making the raw materials and recycle them burden free at the end of life.
  - Practitioner response: Davies does take the burden of end of life of the products, they receive a partial credit during remanufacturing [when?] for avoided burden of the steel when recycling pieces removed when resizing the panels. Davies also takes the burden of disposing of the materials removed from the OEM Core replaced during remanufacture along with the burden of the new replacement materials. At end of life Davies receives an avoided burden for the steel panel frames and steel file storage that can be recycled but takes the burden of the disposal and waste treatment of the other materials not recyclable.
  - Panel response: Taking avoided burden of steel when recycling pieces removed when resizing panels is double counting, which must be avoided. The recycled steel should receive 0 burden/impact when recycled as part of the manufacturing process.
  - Practitioner response: The recycling credit was removed from the independent life cycle comparison. This resulted in a slight increase of the impacts for the Reman 1 life cycle. Normalized Impacts for Reman 1 and Reman 2 are now similar.





- Panel: requirement met

Editorial Comments

- See comments included in the track changes in *Life Cycle Analysis Results: Davies Results* document.
- See additional editorial/grammatical comments in tracked changes of *Life Cycle Analysis Results: Davies Results* document, dated October 7, 2016.
- Panel: editorial comments appropriately addressed

12. Critical Review Letter of Compliance

November 29, 2016

Allen Luccitti
Golisano Institute for Sustainability
Center of Excellence for Sustainable Manufacturing
Rochester Institute of Technology

RE: Panel review of *Life Cycle Assessment Results: Comparison of a remanufactured Steelcase Avenir® office system at Davies Office, Inc. to an OEM office system.*

Dear Mr. Luccitti,

The Golisano Institute for Sustainability conducted a life cycle assessment comparing a remanufactured Steelcase Avenir® office system to an OEM office system. The New York State Pollution Prevention Institute at RIT was asked by GIS to chair a peer review panel of the GIS report to ensure conformance with ISO 14044 for a life cycle assessment comparative assertion with the intent to disclose the results to the public. The peer review panel consisted of three members: Dr. Anahita Williamson; Thaddeus Owen, Sr. Engineer, Sustainability, Herman Miller and Owner OTEC LLC; and Roy Green, HBF & Gunlocke. The LCA report was provided to the panel for review to determine if:

- The methods used to carry out the LCA are consistent with ISO 14040 and 14044
- The methods used to carry out the LCA are scientifically and technically valid
- The data used are appropriate and reasonable in relation to the goal of the study
- The interpretations reflect the limitations identified and the goal of the study
- The study report is transparent and consistent

The panel reviewed three versions of the report and provided GIS with comments regarding assumptions, data sources, interpretations, limitations and transparency of the report. The intent was not to re-do the life cycle assessment or independently validate input data, particularly that from other sources. The panel made recommendations for further work that would address unknowns and issues raised by the review. GIS responded to those comments through subsequent iterations of the report and comment cycles. The final version of the report, titled *Life Cycle Assessment Results: Comparison of a remanufactured Steelcase Avenir® office system at Davies Office, Inc. to an OEM office system* and dated November 16, 2016 is ISO 14044 compliant.

The panel contends that GIS has satisfactorily addressed the substantive and editorial issues raised in the draft LCA reports. The analysis and report follow accepted LCA principles and methodologies and follows the ISO 14040 and 14044 standards. The analysis used accepted commercially available software to perform calculations and retrieve data that was not available.

The panel reviewed the data used in the study and found that appropriate and reasonable data sets were used in relation to the goal of the study. Furthermore, interpretations of the results reflect the assumptions and sensitivity analyses performed in the study.

This letter, along with the *Panel review of Life Cycle Assessment Results: Comparison of a remanufactured Steelcase Avenir® office system at Davies Office, Inc. to an OEM office system* which summarizes the panel's review comments and practitioner responses, must be included in the final LCA report, as required by ISO 14044.

Kate Winnebeck, LCACP
Senior Environmental Health and Safety Specialist