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Life Cycle Assessment of Office Furniture Products

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Life cycle assessment of office furniture products

by
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Executive summary

An increasingly important concern for indoor work environments is the environmental quality of the office space. Building- and insulation materials have often polluted the indoor air by off-gasing harmful substances, such as asbestos, formaldehyde, and others. Recently, environmental concerns have also extended to painting-, flooring/carpeting-, and furnishing materials, leading to related environmental regulation and certification schemes.

Office furniture companies complied with these environmental standards through the development and marketing of less harmful products. As an instrument to gain competitive advantage, the office furniture industry has adopted environmental product performance beyond mere environmental compliance. As a result, today's environmental performance not only refers to the final product but the entire value chain along which a product is developed, manufactured, delivered, used, and retired.

This study focused on the life cycle assessment of environmental impacts related to three different pieces of Steelcase office furniture, which represented the three most common types of office furniture used (lateral file-, work surface-, and panel products). Life cycle assessment was conducted across five environmental impact categories, which were 'energy resource consumption', 'global warming potential', 'acidification potential', 'criteria pollutants', and 'solid waste'. Supporting data was collected and analyzed from almost 50 suppliers, two Steelcase operations, five waste management facilities, and various established databases. In all, the study reflected nearly 250 Steelcase manufacturing steps, 75

primary and secondary materials, and 250 tonkilometers in transportation.

Environmental impacts for all three office furniture product systems were retrieved from live cycle modeling in SimaPro. Overall, the energy resources consumed were 1520 MJ for the work surface, 2410 MJ for the lateral file, and 3730 MJ for the panel. Global warming potentials were 91 kg CO_2 eqv. for the work surface, 219 kg CO_2 eqv. for the lateral file, and 230 kg CO_2 eqv. for the panel. Acidification potentials ranged from 42 H^+ mol eqv. for the lateral file, to 44 H^+ mol eqv. for the work surface, and 82 H^+ mol eqv. for the panel. Criteria pollutants were 0.0145 DALYs for the work surface, 0.0159 DALYs for the lateral file, and 0.024 DALYs for the panel. Solid waste accrued at quantities of 60 kg for the work surface, 67 kg for the panel, and 69 kg for the lateral file. Fig. E-1 depicts environmental impacts for the product systems evaluated.

Five significant effects were uncovered. First, most environmental impacts were caused by material production. This was due to product system material intensities and low recycled contents. Impacts related to plastic- and aluminum production were disproportionately high. Second, 97%–99% of environmental impacts related directly to Steelcase operations came from electricity consumption for powder coating, machinery, welding, and compressed air. Third, material recovery at product end-of-life was low and led to considerable amounts of solid waste. Fourth, manufacturing waste was significant, in some cases, particularly due to powder coating overspray. Fifth, steel performed relatively well in terms of environmental impacts if used resourcefully.

Smaller, however noteworthy effects were criteria pollutants released from diesel trailers/-trucks and dissimilar Steelcase ventilation needs depending on manufacturing location climate conditions.

For the lateral file product system, steel was the major contributor to total environmental impacts, simply due to the fact that steel constituted 97% of the product system total weight (Table E-1). PET production for thin-film powder accounted for up to 13.4% (criteria pollutants) in impact category totals despite its absolute mass contribution to the product system total of only 2%. For solid waste, production of 4 grams of copper – mainly related to welding tips – caused 1.1% of product system total

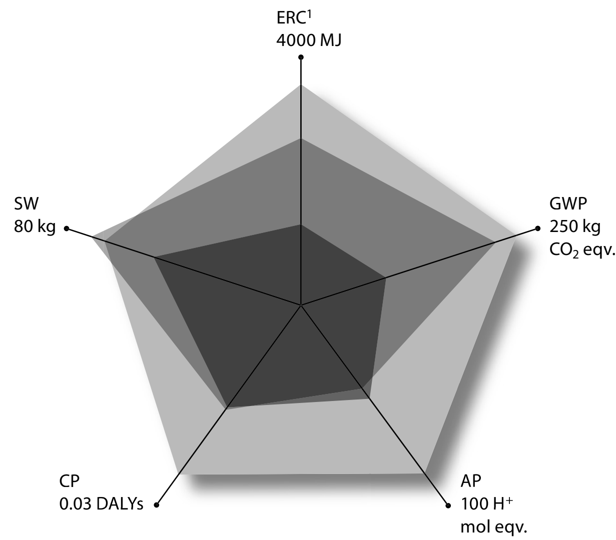

Fig. E-1
Product system environmental impacts for various impact categories

1 ERC = Energy resource consumption
GWP = Global warming potential
AP = Acidification potential
CP = Criteria pollutants
SW = Solid waste
2 Total product system weight

solid waste. Less than 2% of environmental impacts for any given impact category were caused by suppliers as the lateral file product system was predominantly produced in-house. Powder coating operations at Steelcase, as a major electricity consumer, caused up to 15.4% (acidification potential) in product system impact totals.

For the panel product system, aluminum (25% recycled content) and steel were the major contributors to total environmental impacts, ranging from 8.4% to 27.5% (depending on impact category) for steel and 13.2% to 35.6% (depending on impact category) for aluminum (Table E-2). Cardboard (for packaging) and plastic production (excluding PET) accounted for up to 7.1% (acidification potential) and 7.3% (energy resource consumption) in total environmental impacts respectively. Production of 17 grams of copper for electrical receptacles generated 4.2% of panel product system total solid waste. Between 1.7% and 17% (depending on impact category) in total environmental burdens for the panel product system were related to suppliers (alumi-

Table E-1 Major contributors to total lateral file product system environmental impacts

Life cycle stages	**Impact category[1]**				
Materials/Processes	**ERC**	**GWP**	**AP**	**CP**	**SW**
Material production[2]					
Steel (97 %)	68.9 %	80.9 %	46.9 %	49.8 %	17.6 %
PET[3] (2 %)	-	2.6 %	11.4 %	13.4 %	-
Copper (welding tips)	-	-	-	-	1.1 %
Supplier manufacturing					
Steel transforming	1.2 %	-	1.9 %	1.5 %	1.5 %
Steelcase manufacturing					
Powder coating	9.0 %	5.8 %	15.4 %	7.9 %	7.9 %
Welding	2.9 %	2.0 %	5.2 %	2.7 %	2.7 %
Compressed air	1.8 %	1.3 %	3.5 %	2.0 %	2.0 %
Machinery	1.4 %	1.1 %	2.9 %	1.6 %	1.6 %
End-of-life	-	-	-	-	71.0 %

Table E-2 Major contributors to total panel product system environmental impacts

Life cycle stages	**Impact category[1]**				
Materials/Processes	**ERC**	**GWP**	**AP**	**CP**	**SW**
Material production[2]					
Aluminum (16 %)	35.6 %	25.1 %	29.9 %	23.3 %	13.2 %
Steel (52 %)	20.3 %	27.5 %	11.0 %	18.0 %	8.4 %
Cardboard (10 %)	-	5.4 %	7.1 %	6.5 %	2.7 %
Glass fiber (16 %)	8.1 %	-	-	-	-
Plastics (excl. PET; 4 %)	7.3 %	5.2 %	7.0 %	5.0 %	-
Copper (0.03 %)	-	-	-	-	4.2 %
Supplier manufacturing					
Aluminum casting	10.5 %	10.4 %	17.0 %	13.1 %	-
Zinc electroplating	1.7 %	2.0 %	2.0 %	2.0 %	-
Steelcase manufacturing					
Powder coating	2.0 %	2.0 %	2.5 %	3.1 %	1.2 %
Machinery	1.6 %	1.6 %	2.0 %	1.1 %	-
Welding	1.4 %	1.4 %	1.8 %	-	-
End-of-life	-	-	-	-	63.0 %

num casting and electroplating zinc). Manufacturing activities at Steelcase contributed up to 3.1% (depending on impact category) to the panel product system total impacts (almost exclusively due to electricity usage).

For the work surface product system, the majority of contributions to total environmental impacts came from aluminum-, laminate-, steel-, and particleboard production (Table E-3). Supplier manufacturing accounted for up to 6.5% in total impacts (depending on impact category) for aluminum casting. Impact contributions related to Steelcase activities ranged between 1.1% and 4.3% (depending on impact category) of product system total impacts.

Product end-of-life for all product systems accounted for considerable impacts only with respect to solid waste. On average, recycling rates for the U.S. municipal waste management system were low (29%) leading to incineration (15%) and landfilling (56%) of the larger fraction of each discarded product system.

Overall, this study was intended to provide internal Steelcase stakeholders working in design, engineering, sourcing, manufacturing, and marketing with knowledge that could be applied towards design improvements of Steelcase office furniture product systems. By including the results with other criteria, more informed decisions can be made regarding product development, manufacturing, and life cycle product stewardship.

Table E-3 Major contributors to total work surface product system environmental impacts

Life cycle stages	**Impact category**[1]				
Materials/Processes	**ERC**	**GWP**	**AP**	**CP**	**SW**
Material production[2]					
Laminate (10 %)	19.3 %	9.0 %	26.9 %	20.4 %	2.3 %
Aluminum (5 %)	19.3 %	17.2 %	24.4 %	18.7 %	22.3 %
Particleboard (49 %)	19.3 %	15.6 %	14.3 %	9.4 %	-
Steel (31 %)	16.8 %	33.6 %	7.6 %	11.1 %	3.5 %
Supplier manufacturing					
Aluminum casting	5.2 %	5.6 %	6.5 %	5.2 %	1.0 %
Steelcase manufacturing					
Machinery	3.6 %	4.3 %	3.1 %	3.3 %	1.1 %
Powder coating	2.4 %	2.9 %	2.3 %	2.1 %	-
Welding	2.0 %	2.4 %	2.0 %	1.8 %	-
Compr. air	1.3 %	1.6 %	1.2 %	1.2 %	-
Particleboard	-	-	-		11.1 %
End-of-life	-	-	-	-	55.0 %

1 ERC = Energy resource consumption
GWP = Global warming potential
AP = Acidification potential
CP = Criteria pollutants
SW = Solid waste
2 Percentages in brackets indicate fraction for material of total product system weight
3 PET = Polyethylene-Terepthalate

Acknowledgements

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As much as a well conceived scientific approach is conducive to any research like this, so are the many resourceful individuals who contributed their accrued and specific expertise as well as, based on a more visionary commitment, created the very foundation for this project in material and strategic respects.

I would like to give all of them my best wishes and hope that their willingness will persevere to foster future projects geared towards the refinement of the field of Industrial Ecology in general and the continuous advancement of Steelcase Corporation as a cutting edge business in particular.

Wege foundation[1]

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1 Individuals are listed in alphabetical order.
2 At Steelcase Grand Rapids, Michigan, and Athens, Alabama, facilities. For confidentiality purposes not all individuals involved are mentioned.

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1. Project description

This chapter begins with the motivation for this study, and the general framework applied to conduct it. The objectives and goals for the project are described, as well as the reasoning behind choosing three products as subjects for life cycle assessment. Finally, Section [1.5.] portrays the product systems in terms of their specific assembly and design.

1.1. Introduction and background

Introduction

In 2003 Steelcase Inc. in Grand Rapids, Michigan, and the Center for Sustainable Systems at the University of Michigan's School of Natural Resources and Environment, Ann Arbor, embarked upon an extended project on life cycle assessment for office furniture products. Steelcase Inc., a leading business in work place solutions, found itself in an increasingly competitive market regarding environmental product performance. Through expanding customer awareness at international as well as national levels, environmental issues regarding office furniture products developed from a predominantly indoor-air-quality focus to a much broader product-life-cycle based subject.[1]

In general, a product life cycle not only comprises a product's use phase – as in the case of mere indoor-air-quality measures – but also previous as well as subsequent life cycle stages such as raw-material acquisition and -processing, manufacturing, packaging, distribution, use, and product retirement. Fig. 1.1.-1 depicts a generic life cycle system.

Besides recent efforts related to new product development[2], this was the first time Steelcase Inc. attempted to evaluate the environmental performance of existing products at such a broad scale. The Center for Sustainable Systems was chosen to collaborate with Steelcase, based on its long-standing expertise in research on pollu-

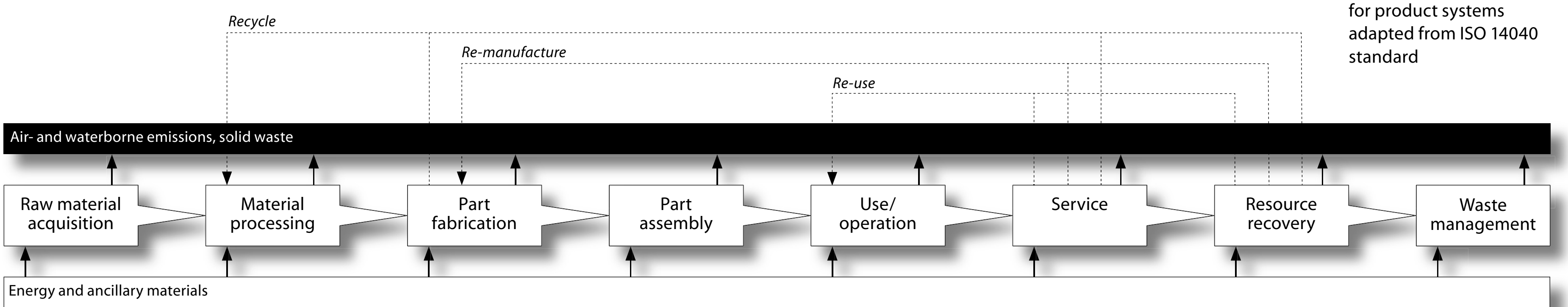


Fig. 1.1.-1
Generic life cycle system for product systems adapted from ISO 14040 standard

tion prevention and life cycle assessment.

This study report provides a description of the framework, methods, results, and insights applied and derived from this project. It marks the end of approximately nine months of research and eventually provides recommendations for implementing life cycle design into Steelcase day-to-day operations.

Background

The U.S. office furniture industry during the past five years has undergone a major consolidation process.[3] Several smaller businesses were bought out, bigger companies diversified and expanded overseas.[4] The competition in domestic markets became fiercer, in particular due to an economic downturn triggered by the burst of the "internet bubble" in the late 1990s and increased competition from overseas, especially from China.[5] At the same time, new workplace models emerged where environmental concerns regarding office environments in general were brought forward by workers, employers and ultimately real estate owners trying to market their properties.[6] Major federal regulations concerning environmental protection were put in place starting in the late 1980s (Community Right-to-Know Act, 1986; Clean Air Act, 1990; Pollution Prevention Act, 1990; etc.), which substantially also affected the U.S. furniture industry. For instance, 20 million tons of volatile organic components (VOCs) were released by U.S. furniture manufacturers through finishing- and spraying processes in 1992, which became subject to strong regulation under the Clean Air Act due to carcinogenic effects.[7] Subsequently, various environmental certification schemes emerged, in particular addressing the office furniture-, interior design-, and building industries by providing labeling systems for improved environmental performance (GREENGUARD™, LEED®, etc.).[8] Many of those schemes have become useful communication tools in today's market place.

With respect to Steelcase Inc., first environmental activities started about 20 years ago mainly in order to manage regulatory compliance issues more effectively.[9] According to Walley and Whitehead this can be regarded as a stage of "embracing without innovating" where companies strive for significant improvements in waste management without fundamentally changing actual pollution-generating processes.[10] As in the case of Steelcase, related functions have been assigned mainly to environmental specialists inside the occupational safety and -health program[9]. As shown by Porter and van der Linde, however, this oftentimes has facilitated narrow and incremental end-of-pipe solutions only.[11] As such, and as public and private awareness increased, policies – also at Steelcase Inc. - eventually shifted from mere waste management strategies to more integrated technologies focusing on pollution prevention (e.g. substituting powder coating for wet-painting processes).

In general, Steelcase has embraced environmental issues alongside broader communal responsibilities:

"Steelcase is committed to protecting the global, local and work side environment wherever we do business. Our goal is to be proactive and continually incorporate environmental, health and safety considerations into

1 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; July 7, 2003

Myerson, Jeremy; Health Is Wealth in the Workplace; Management Today; London, UK; June 1991, p. 82

2 For example 'PLEASE – 468 150 MHD' chair; Environmental Product Declaration; Steelcase Inc., Grand Rapids, MI, USA; 2004

3 Coleman, Katie; Office Furniture Makers Seeing Double-Green; WOOD & WOOD products; USA; Dec. 2004; www.iswonline.com/wwp/200412/soi.cfm

"The US office furniture industry shows a high degree of concentration: six companies account for 50% of the market."; www.2f.com.cn/e/news/hutitle.asp?newsid=118

4 Iwanski, John; Office Furniture Industry Back on Track; WOOD& WOOD products; USA; May 2000; www.iswonline.com/wwp/200005/25ofurn.htm

5 "The U.S. office furniture market peaked in 2000 with $13.3 billion in shipments. Since then, shipments have dropped every year, falling to $8.5 billion last year." – Gold, Robert; Office furniture industry optimistic about business; The Holland Sentinel; USA; Feb. 10, 2004; www.thehollandsentinel.net/stories/082004/loc_082004033.shtml

6 Sustainable Development Issues Scan: Office Furniture Industry; Five Winds International; Canada; Nov. 2003

7 McMorrow, Eileen; Furniture for a greener future; Facilities design & Management; USA; May 1992; p. 45

8 GREENGUARD Environmental Institute; USA; 1996; www.greenguard.org

LEED – Leadership in Energy and Environmental Design; Green Building Council; USA; 2000; www.usgbc.org

9 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; July 7, 2003

10 Walley, N.; Whitehead, B.; It's not easy being green; Harvard Business Review 72; USA; 1994; p. 46–52

11 Porter, M.; van der Linde, C.; Green and competitive; Harvard Business Review 73; USA; 1995; p. 120–134

our products, activities, and services. We will continually meet or exceed all applicable environmental requirements".[1]

However, the initial reactive/receptive approach to environmental action[2] at Steelcase has expanded recently when the potential for competitive advantage set off a more proactive attitude.[3] Under the impression that prevention is cheaper than cure and that most of the cost of a product and its production process (also in terms of environment) are committed in the design phase, exemplary projects have been conceived that integrate environmental considerations from an early stage on.[4] Prior to that, environmental issues such as workers health & safety, ancillary substances/consumables, banned materials lists, material-/process-/product fact sheets, recycled content, recyclability and others were tackled in a rather isolated fashion. In order to avail itself of the full spectrum of environmental benefits such as reduced liability, product-/process innovation, cost reduction and positive customer- and public perception, however, Steelcase must be fully committed to considering environmental concerns as part of total quality management (TQM). As such, organizations act as a whole including executives, workers, customers, suppliers, and neighbors by adopting total quality environmental management (TQEM) throughout planning and operations processes.[5] This also implies the application of accountability tools and strategies across various functional entities.

In 1996, the ISO 14000 certification system was introduced building on the success and acceptance of the older ISO 9000 standard. ISO 14000 extended the ISO 9000 quality certification system into the environmental realm assessing the extent to which a company is environmentally responsible in three categories:[6]

- Environmental monitoring- and controlling systems (measurement, assessment and management of emissions, effluents, and other similar waste streams)
- Operations (natural resource use, energy consumption, and number of incidents)
- Management systems (systems development and -integration as well as the introduction of environmental concerns into general business)

Related to the category 'management systems', the standard provides an instructive subset – ISO 14040 – which establishes life cycle assessment (LCA) as a viable tool for environmental improvement along the entire value chain.[7] In this study LCA was applied to Steelcase specific products as a means to further comprehensive environmental management activities.

1.2. Project objectives

The objective of this project is to identify and document the potential for environmental improvements within the Steelcase product portfolio by examining three pieces of actual Steelcase office furniture. The product systems are introduced in greater detail in Sections [1.4.] and [1.5.]. The specific objectives for this project include:

- Apply an approved life cycle assessment framework like the ISO 14040 standard to evaluate the overall environmental performance of a file storage cabinet, a panel element as used in office cubicle systems, and a work surface/desk product
- Identify primary and secondary data sources for life cycle assessment at Steelcase operations, third parties, such as suppliers, and within publicly accessible sources and databases
- Communicate life cycle environmental impacts associated with these three products to various Steelcase stakeholders via specific impact indicators
- Identify key drivers of environmental performance, such as specific materials, processes, and design strategies used for each product system
- Demonstrate the value of LCA to support future product development for Steelcase

1.3. Project goal and significance

The goal of this project is to develop prototypical life cycle profiles of three office furniture products currently produced by Steelcase Corporation at its Grand Rapids, Michigan, and Athens, Alabama, facilities. Also, the project points out to the various internal stakeholders the environmental burdens associated with general types of Steelcase office furniture products and opportunities for improvement. Eventually, the results may guide the establishment of a more integrated life cycle design process at Steelcase.

On a long-term perspective, the goal is to raise awareness for direct and indirect, yet specific, environmental impacts related to Steelcase products, and thus, to stimulate product stewardship along the entire Steelcase value chain. This research, although focusing predominantly on aspects of product design and -development, manufacture, facility operation, and transportation, was designed to provide an important means to this end.

1 “Responsibilities to Our Worldwide Communities – Protecting the Environment”; Steelcase promotional material; Grand Rapids, MI; Aug. 2003
2 Winsemius, P.; Guntram, U.; Responding to the environmental challenge; Business Horizons 35; USA; 1992
3 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; July 7, 2003
4 For example ‘PLEASE – 468 150 MHD’ chair; Environmental Product Declaration; Steelcase Inc., Grand Rapids, MI, USA; 2004
5 Makower, J.; Beyond the Bottom Line; Simon and Schuster; New York, NY; USA; 1994
6 Handfield, Robert B., et al.; ‘Green’ value chain practices in the furniture industry; Journal of Operations Management 15; USA; 1997
7 The conduct of a life cycle assessment is described in greater detail in Section [ ]

1.4. Product system selection

The following three furniture product systems were examined during this study (Steelcase terminology is used in naming). Actual product compositions (parts, assemblies, etc.) are introduced in greater detail in Section [1.5.]:

- "Answer" Lateral File
- "Answer" Panel Configuration 66 x 48
- "Universal" Corner, Straight-Front Worksurface

The products were chosen based on how well they represented the first three of five main office furniture categories covered by Steelcase products, which are storage-, panel-, work surface-, seating-, and lighting products. Moreover, the products picked accounted for a substantial percentage in sales concerning their respective categories and in comparison to the category's total sales in 2002 (baseline year).[1] The selected lateral file product system, for instance, led the category 'storage products' for the 'Answer' product line. For the category 'work surfaces' the decision was based on sales for universal (modular) support legs, which can be attached flexibly to various types and shapes of actual work surfaces (desk tops). The single post leg and the double post C-leg, both were at the top of the according category. Concerning the panel product system, a general choice regarding the panel size was made in line with sales numbers for basic frame elements that made up for a substantial percentage in frame package sales. From there, choices for the specific panel surface configuration (slatwalls, acoustic fibers, etc.) were instructed by internal Steelcase marketing experience. In terms of procedure, the selection process was undertaken by a group of Steelcase staff and the author during a meeting at the beginning of the study in June 2003.

1.5. Product system description

Fig. 1.5.-1 depicts a work place setup typical for most of today's professional office spaces. Modular panel components structure open building floors and thus create individual work environments, which allow for privacy without fully isolating the work force from each other. Furthermore, the cubicle systems are designed to be flexible in order to facilitate changes in spacial arrangements over time and to use office space more efficiently.

Sections [1.5.1.] through [1.5.3.] introduce the investigated product systems as actual physical artefacts within the Steelcase portfolio and document their reference numbers (Ref.#) and locations within Steelcase communication materials.

Fig. 1.5.-1
Showcase Steelcase Answer office furniture setup with storage-, seating-, work surface-, and panel product systems (left to right).

1 Sales, here, referred to the actual numbers of product systems sold (in contrast to the amount of revenue generated)

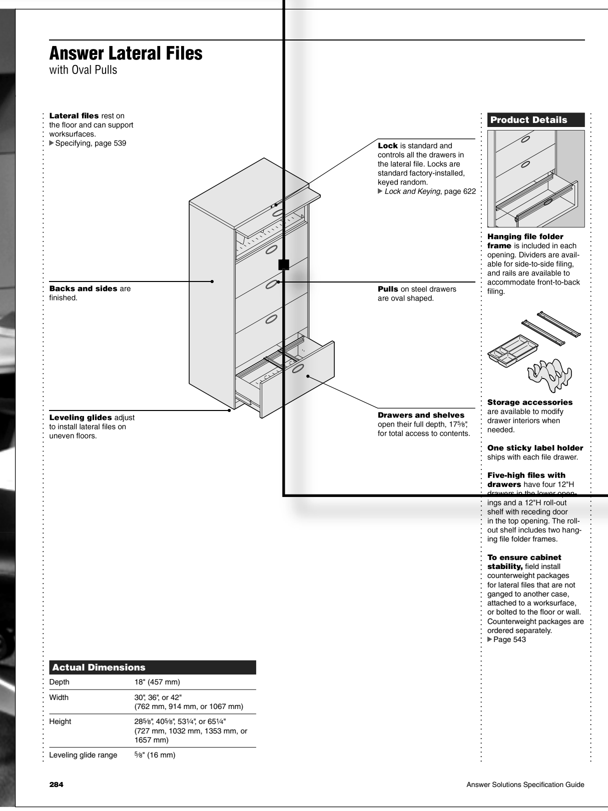
1.5.1. Lateral file product system

The storage product system chosen is a freestanding single unit comprising three drawers and a metal top as shown in Fig. 1.5.1.-1. It is mainly made out of steel and equipped with plastic oval pulls. Table 1.5.1.-1 shows the Steelcase reference number for this product system.

Table 1.5.1.-1 Steelcase reference numbers

Item	**Ref.#**
Lateral File	TS700336L

Fig. 1.5.1.-1
Storage product system within Steelcase Answer office furniture setup.



Answer Lateral Files
with Oval Pulls

Lateral files rest on the floor and can support worksurfaces.
▶ Specifying, page 539

Backs and sides are finished.

Leveling glides adjust to install lateral files on uneven floors.

Lock is standard and controls all the drawers in the lateral file. Locks are standard factory-installed, keyed random.
▶ *Lock and Keying*, page 622

Pulls on steel drawers are oval shaped.

Drawers and shelves open their full depth, 17⅝", for total access to contents.

Product Details

Hanging file folder frame is included in each opening. Dividers are available for side-to-side filing, and rails are available to accommodate front-to-back filing.

Storage accessories are available to modify drawer interiors when needed.

One sticky label holder ships with each file drawer.

Five-high files with drawers have four 12"H drawers in the lower openings and a 12"H roll-out shelf with receding door in the top opening. The roll-out shelf includes two hanging file folder frames.

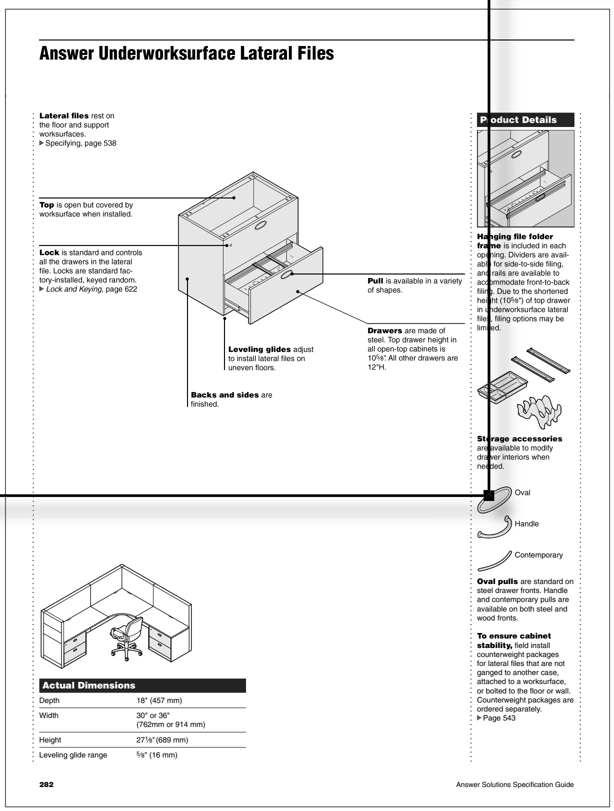
To ensure cabinet stability, field install counterweight packages for lateral files that are not ganged to another case, attached to a worksurface, or bolted to the floor or wall. Counterweight packages are ordered separately.
▶ Page 543

Actual Dimensions

Depth	18" (457 mm)
Width	30", 36", or 42" (762 mm, 914 mm, or 1067 mm)
Height	28⅝", 40⅝", 53¼", or 65¼" (727 mm, 1032 mm, 1353 mm, or 1657 mm)
Leveling glide range	⅝" (16 mm)

284 Answer Solutions Specification Guide

Fig. 1.5.1.-2
Page 284 of the Steelcase Answer Spec-Guide showing the general type of lateral file chosen.[1] The specific model used in this research comes with three drawers.



Answer Underworksurface Lateral Files

Lateral files rest on the floor and support worksurfaces.
▶ Specifying, page 538

Top is open but covered by worksurface when installed.

Lock is standard and controls all the drawers in the lateral file. Locks are standard factory-installed, keyed random.
▶ *Lock and Keying*, page 622

Pull is available in a variety of shapes.

Drawers are made of steel. Top drawer height in all open-top cabinets is 10⅝". All other drawers are 12"H.

Leveling glides adjust to install lateral files on uneven floors.

Backs and sides are finished.

Actual Dimensions	
Depth	18" (457 mm)
Width	30" or 36" (762mm or 914 mm)
Height	27⅛" (689 mm)
Leveling glide range	⅝" (16 mm)

Product Details

Hanging file folder frame is included in each opening. Dividers are available for side-to-side filing, and rails are available to accommodate front-to-back filing. Due to the shortened height (10⅝") of top drawer in underworksurface lateral files, filing options may be limited.

Storage accessories are available to modify drawer interiors when needed.

Oval

Handle

Contemporary

Oval pulls are standard on steel drawer fronts. Handle and contemporary pulls are available on both steel and wood fronts.

To ensure cabinet stability, field install counterweight packages for lateral files that are not ganged to another case, attached to a worksurface, or bolted to the floor or wall. Counterweight packages are ordered separately.
▶ Page 543

282 Answer Solutions Specification Guide

Fig. 1.5.1.-3
Page 282 of the Steelcase Answer Spec-Guide showing the specific oval pulls chosen.[1]

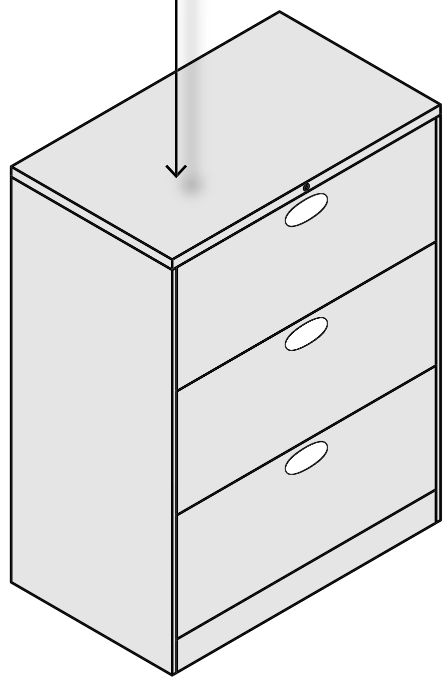


Fig. 1.5.1.-4
Answer lateral file product system investigated in this research project.

1 Steelcase Spec-Guides can be viewed online at www.steelcase.com

1.5.2. Panel product system

The panel product system selected is a single element of a modular cubicle scheme for structuring interior office spaces. The basic components of panel-based systems like this one are an internal metal frame, various skin elements to fulfill different needs, such as pinning documents, dampening noise, supporting accessories etc., and electrical wiring. The panel product system is predominantly made out of steel, aluminum, plastics, and fiberglass. Table 1.5.2.-1 shows the Steelcase reference numbers for this product.

Table 1.5.2.-1 Steelcase reference numbers

Item	**Ref.#**
Package-frame, horizontal, 48	TS748HF
Junction-end of run, 66	TS766EPJ
Junction-inline, 66	TS766IPJ
Skin-tack. acoustical, 60x48	TS76048TK
Skin-tack. acoustical, 24x48	TS72448TK
Skin, slatwall-answer, 24x48	TS72448SW
Technology skin 12x48	TS71248TS
Receptacle-15Amp, line-1, 2+2	TS71SSY
48 Power kit, 2+2	TS7PK48Y

Fig. 1.5.2.-1
Panel product system within Steelcase Answer office furniture setup.

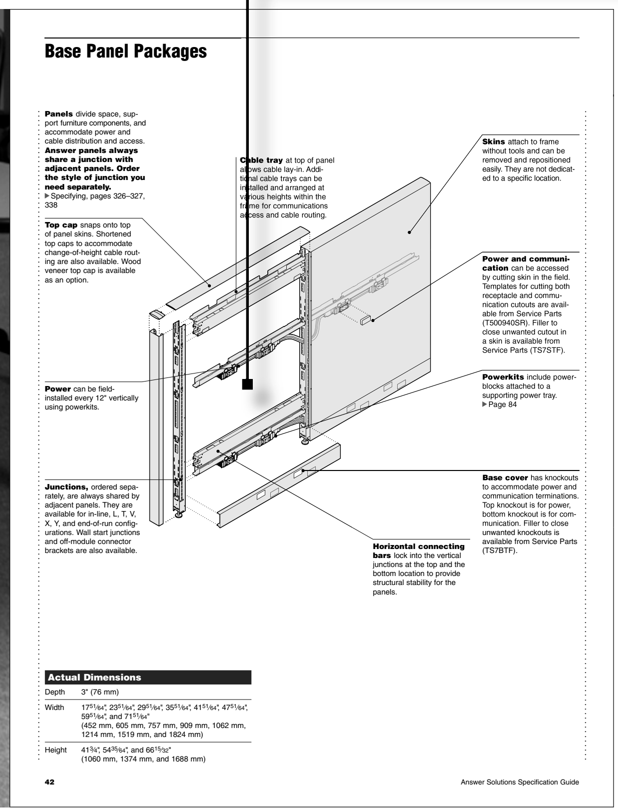


Fig. 1.5.2.-2
Page 42 of the Steelcase Answer Spec-Guide showing the basic structure of Answer panel elements composed of a metal frame, various skin elements, edge coverings, and electrical wiring.

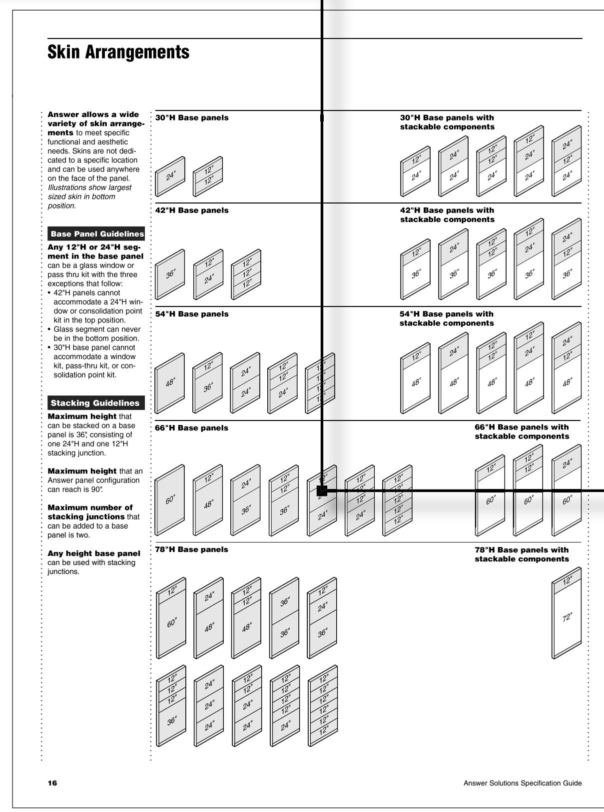
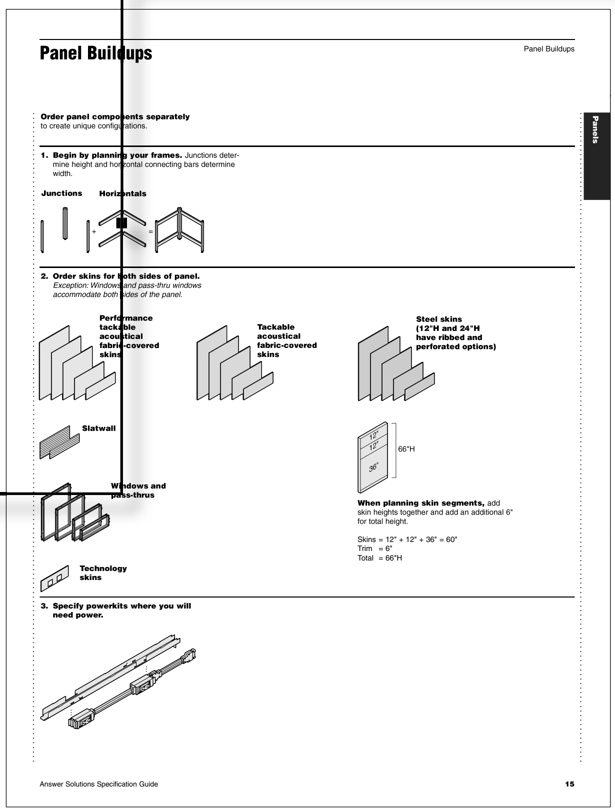


Fig. 1.5.2.-3
Page 16 of the Steelcase Answer Spec-Guide showing the specific skin arrangement chosen.[1] The components are a tackable acoustical skin, a technology skin, and a slatwall element on the front side of the panel element and a tackable acoustical skin on its backside.


Panel Buildups

Panel Buildups

Panels

Order panel components separately
to create unique configurations.

1. **Begin by planning your frames.** Junctions determine height and horizontal connecting bars determine width.

2. **Order skins for both sides of panel.**
Exception: Windows and pass-thru windows accommodate both sides of the panel.

When planning skin segments, add skin heights together and add an additional 6" for total height.

Skins = 12" + 12" + 36" = 60"
Trim = 6"
Total = 66"H

3. **Specify powerkits where you will need power.**

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Fig. 1.5.2.-4
Page 15 of the Steelcase Answer Spec-Guide showing the general frame components for the panel element chosen.[1]

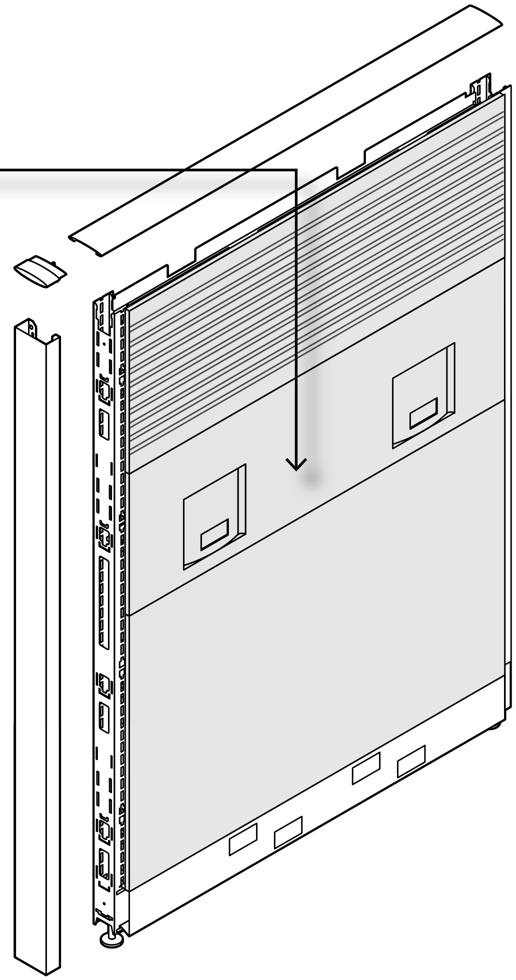


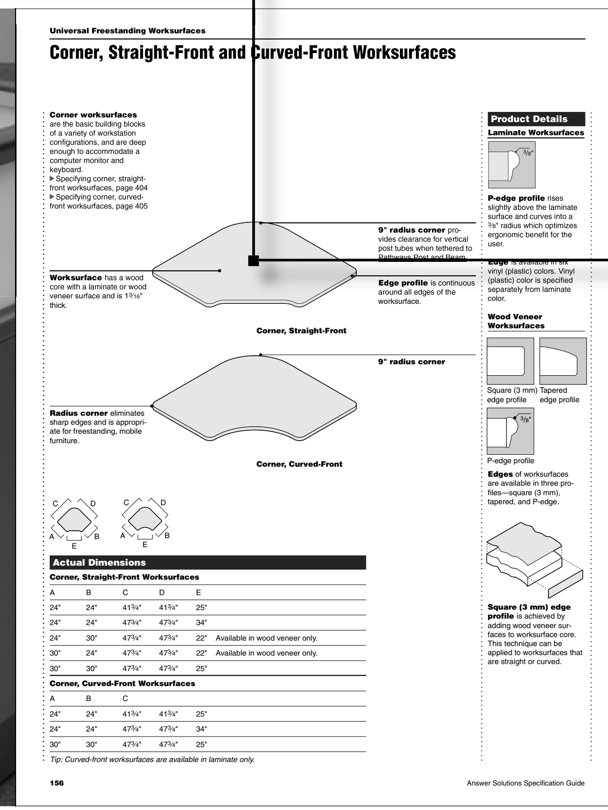
Fig. 1.5.2.-5
Front side of the Answer panel element as used in this research project.

1 Steelcase Spec-Guides can be viewed online at www.steelcase.com

1.5.3. Work surface product system

The office desk chosen is a freestanding single work unit comprising a particleboard work surface coated with laminate as shown in Fig. 1.5.3.-1 and Fig. 1.5.3.-2 and three individual legs as shown in Fig. 1.5.3.-3. Two of those legs are Double Post C-Legs mainly made out of steel and aluminum. The remaining leg is a Single Post Leg made out of steel. The legs are attached to the work surface via screws. The fully assembled unit can be seen in Fig. 1.5.3.-4. Table 1.5.3.-1 shows the Steelcase reference numbers for the three major components.

Fig. 1.5.3.-1
Work surface product system within Steelcase Answer office furniture setup.



Universal Freestanding Worksurfaces

Corner, Straight-Front and Curved-Front Worksurfaces

Corner worksurfaces are the basic building blocks of a variety of workstation configurations, and are deep enough to accommodate a computer monitor and keyboard.
▶ Specifying corner, straight-front worksurfaces, page 404
▶ Specifying corner, curved-front worksurfaces, page 405

Worksurface has a wood core with a laminate or wood veneer surface and is 1 3/16" thick.

9" radius corner provides clearance for vertical post tubes when tethered to Pathways Post and Beam.

Edge profile is continuous around all edges of the worksurface.

Corner, Straight-Front

9" radius corner

Radius corner eliminates sharp edges and is appropriate for freestanding, mobile furniture.

Corner, Curved-Front

Actual Dimensions

Corner, Straight-Front Worksurfaces

A	B	C	D	E	
24"	24"	41¾"	41¾"	25"	
24"	24"	47¾"	47¾"	34"	
24"	30"	47¾"	47¾"	22"	Available in wood veneer only.
30"	24"	47¾"	47¾"	22"	Available in wood veneer only.
30"	30"	47¾"	47¾"	25"	

Corner, Curved-Front Worksurfaces

A	B	C		
24"	24"	41¾"	41¾"	25"
24"	24"	47¾"	47¾"	34"
30"	30"	47¾"	47¾"	25"

Tip: Curved-front worksurfaces are available in laminate only.

Product Details

Laminate Worksurfaces

3/8"

P-edge profile rises slightly above the laminate surface and curves into a 3/8" radius which optimizes ergonomic benefit for the user.

Edge is available in six vinyl (plastic) colors. Vinyl (plastic) color is specified separately from laminate color.

Wood Veneer Worksurfaces

Square (3 mm) edge profile

Tapered edge profile

3/8"

P-edge profile

Edges of worksurfaces are available in three profiles—square (3 mm), tapered, and P-edge.

Square (3 mm) edge profile is achieved by adding wood veneer surfaces to worksurface core. This technique can be applied to worksurfaces that are straight or curved.

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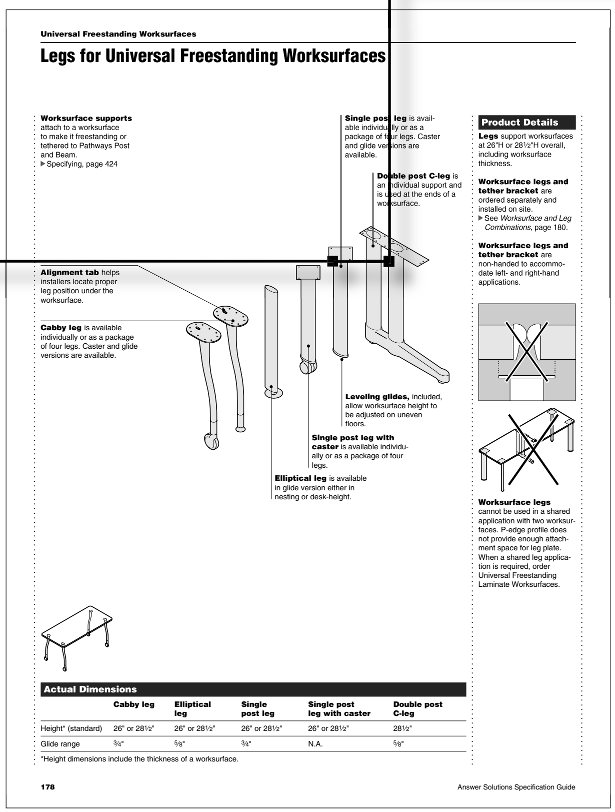
Fig. 1.5.3.-2
Page 156 of the Steelcase Answer Spec-Guide showing the specific wooden desk top chosen.[1]

Table 1.5.3.-1 Steelcase reference numbers

Item	Ref.#
Corner, Straight-Front Worksurface	BFC224848
Single Post Leg	TS7SPL
Double Post C-Leg	TS7CL


Universal Freestanding Worksurfaces

Legs for Universal Freestanding Worksurfaces

Worksurface supports attach to a worksurface to make it freestanding or tethered to Pathways Post and Beam.
▶ Specifying, page 424

Single post leg is available individually or as a package of four legs. Caster and glide versions are available.

Double post C-leg is an individual support and is used at the ends of a worksurface.

Alignment tab helps installers locate proper leg position under the worksurface.

Cabby leg is available individually or as a package of four legs. Caster and glide versions are available.

Leveling glides, included, allow worksurface height to be adjusted on uneven floors.

Single post leg with caster is available individually or as a package of four legs.

Elliptical leg is available in glide version either in nesting or desk-height.

Product Details

Legs support worksurfaces at 26"H or 28½"H overall, including worksurface thickness.

Worksurface legs and tether bracket are ordered separately and installed on site.
▶ See *Worksurface and Leg Combinations,* page 180.

Worksurface legs and tether bracket are non-handed to accommodate left- and right-hand applications.

Worksurface legs cannot be used in a shared application with two worksurfaces. P-edge profile does not provide enough attachment space for leg plate. When a shared leg application is required, order Universal Freestanding Laminate Worksurfaces.

Actual Dimensions

	Cabby leg	Elliptical leg	Single post leg	Single post leg with caster	Double post C-leg
Height* (standard)	26" or 28½"	26" or 28½"	26" or 28½"	26" or 28½"	28½"
Glide range	¾"	⅝"	¾"	N.A.	⅝"

*Height dimensions include the thickness of a worksurface.

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Fig. 1.5.3.-3
Page 178 of the Steelcase Answer Spec-Guide showing the specific table legs, one Single Post Leg, and two Double Post C-Legs chosen.[1]

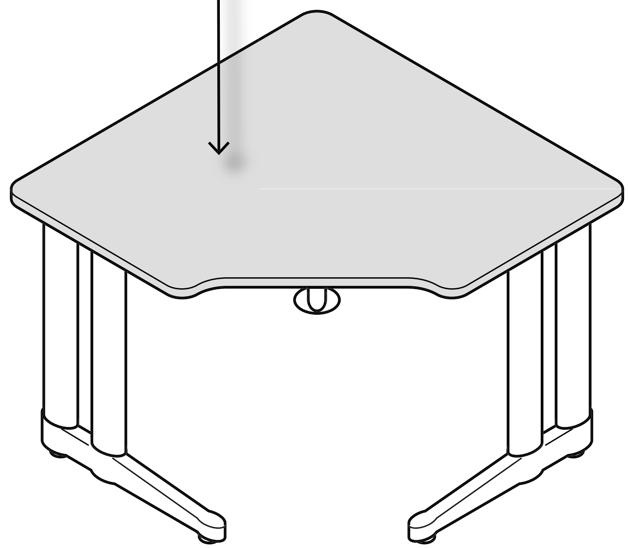


Fig. 1.5.3.-4
Configuration of freestanding Answer Straight-Front Work Surface as used in this research project.

1 Steelcase Spec-Guides can be viewed online at www.steelcase.com

2. Systems analysis

This chapter outlines the scope and related boundaries applied in this study. It also elucidates general assumptions that were made concerning the life cycles of all three product systems under consideration. Finally, the chapter introduces material compositions for the product systems as well as generic process flow diagrams depicting overall product related part- and material flows.

2.1. Project scope

This study looked at the entire life cycle of three Steelcase office furniture product systems, a lateral file-, a panel-, and a work surface product system, from material provision through end-of-life management. With respect to their basic functions the three products are fairly different, however, in combination they describe a standard office set up as found in many office environments today. Due to the products' disparate functional units the study does not provide a direct comparison between the product systems (rather than examining each product individually). Nevertheless, to point out specifics in the life cycle performance of each product system, comparisons are made in Section [4.2.] based on environmental impacts related to product system weight.

Due to the nature of office furniture products, in this study, the environmental impacts caused during their use phase are assumed to be negligible. Unlike other product systems, which, for instance, consume considerable amounts of energy and process materials during their use phase (e.g. household appliances, vehicles, buildings, etc.), office furniture products do not depend on this kind of inputs in order to fulfill their intended functions. As such, impacts related to cleaning- and possible transportation activities (due to relocating, furniture sale-offs, etc.) are considered insignificant, and thus are not evaluated in this study. Environmental burdens concerning the three furniture product systems are reported for the impact categories 'energy resource consumption', 'global warming potential', 'acidification potential', 'criteria pollutants', and 'solid waste'. Impact categories are further discussed in Section [3.3.].

2.2. Product system compositions

Tables 2.2.-1 through 2.2.-3 show the various materials used to manufacture the product systems. The listings include both materials, which became part of the final product system and packaging applied for final product system delivery. In general, type and amount of materials used for each product system were derived from Steelcase internal manufacturing documentation and supplier specifications.[1]

Table 2.2.-1 Material usage in lateral file product system

Materials	Materials used in product (kg)
Steel	
IISI, cold rolled coil	61.200
IISI, hot rolled coil	6.000
Steel total	*67.200*
Aluminum	
AlCuMgPb (2011) I, US	0.051
Aluminum total	*0.051*
Non-ferro	
Zinc	0.033
Non-ferro total	*0.033*
Plastics	
LLDPE film FAL	0.001
LDPE film FAL	0.002
PA 6 I, US	0.009
PA 6.6 A, US	0.020
PE granulate average B250, US	0.002
PET bottle grade I, US	1.390
PVC FAL	0.005
SAN A, US	0.086
Plastics total	*1.513*
Product system total	***68.000***

Table 2.2.-2 Material usage in panel product system

Materials	Materials used in product (kg)
Steel	
IISI, cold rolled coil	26.560
IISI, hot rolled coil	0.141
IISI, welded pipes	2.960
Steel total	*29.661*
Aluminum	
Aluminium 25% rec. B250, US	9.280
Aluminum total	*9.280*
Non-ferro	
Zinc	0.630
Non-ferro total	*0.630*
Plastics	
ABS P, US	0.020
LDPE film FAL	0.835
PA 6 I, US	0.118
PA 6.6 A, US	1.130
PE granulate average B250, US	0.032
PET bottle grade I, US	0.465
PP caps FAL	0.023
Adhesive hot-melt	0.007
Plastics total	*2.630*
Glass	
Fiberglass	9.020
Glass total	*9.020*
Cardboard & paper	
Cardboard	5.840
Cardboard & paper total	*5.840*
Product system total	***57.600***

Table 2.2.-3 Material usage in work surface product system

Materials	Materials used in product (kg)
Steel	
IISI, cold rolled coil	3.010
IISI, welded pipes	9.040
Steel total	*12.14*
Aluminum	
AlCuMg1 (2017) I, US	1.900
Aluminum total	*1.900*
Non-ferro	
Zinc	0.019
Non-ferro total	*0.019*
Plastics	
LLDPE film FAL	0.001
PA 6 I, US	0.032
PA 6.6 A, US	0.001
PET bottle grade I, US	0.351
PMMA beads P	0.014
PP caps FAL	0.113
PVC FAL	0.513
Plastics total	*1.024*
Wood	
Particleboard, US	19.100
Wood total	*19.100*
Laminate	
Front-laminate	1.910
Backer-laminate	1.910
Laminate total	*3.820*
Others	
Cardboard	1.200
Others total	*1.200*
Product system total	***39.100***

1 Further elaborated in Section [3.2.]

2.3. Boundaries and assumptions

The study boundary includes the life cycle phases material production, manufacturing, packaging, delivery, and retirement as laid out in Table 2.3.-1.

Table 2.3.-1 Boundary and assumptions for the life cycle assessment of Steelcase office furniture product systems

Life cycle stage	Boundary and assumptions
General	• Transportation activities between life cycle stages were accounted for at the end of the life cycle stage that is the source of transported materials, subassemblies, assemblies, product systems, etc. For example, transportation for the manufacturing stage was accounted for final products delivered to customers/dealerships, whereas transportation related to materials and subassemblies going into the manufacturing stage were accounted for in the material production stage.
Material production (Raw material acquisition and material processing)	• Environmental data for unit processes regarding material production were taken from standard data sets like Franklin Associates, Buwal, Idemat, etc. Specific unit processes. Associated data sets are listed in Table 3.?. in Section [3.1.]. • Aluminum was accounted for containing 25% recycled material. • Particleboard manufacturing data was derived from BEES[1] plywood data. Transportation activities considered shipping particleboard from a wood products manufacturer to Grand Rapids, Michigan.[2] • Feedstock energy and global warming potential for wood, as a renewable material, was not accounted for in the model. • Data for welding gas did not include energy demands for gas liquefaction.
Manufacturing	• Validation date of all primary data collected at Steelcase sites was August 31, 2003. • Electricity usage was modeled individually for each Steelcase manufacturing site based on the local generation mix. Grand Rapids, Michigan, facilities are served by Consumers Energy utilities. Athens, Alabama, facilities are served by the Tennessee Valley Authority utilities.[3] • Accuracy of information on energy consumption for manufacturing equipment is estimated +/- 25%.[4] • Accuracy of information on manufacturing throughput was estimated +/- 5% (parts/time on a particular piece of machinery).[5] • Electricity- and overhead data collected at Steelcase Kentwood-West (Grand Rapids, Michigan) operations was applied to all Grand Rapids Steelcase facilities. • Overhead was only accounted for manufacturing processes executed at Steelcase facilities. • Overhead comprised electricity-, gas-, steam-, and water consumption for lighting-, ventilation-, heating-, and sanitary purposes. Overhead data were derived from utility bills (Jan. 2003 - Dec. 2003) for the Athens, Alabama, facilities, and from internal costing documentations (Jan. 2002 - Dec. 2002) for the Kentwood-West (Grand Rapids, Michigan) operations.[6] Regarding the Kentwood-West facilities, actual amounts/volumes of energy/materials consumed were re-calculated based on cost/unit of energy carriers such as electricity, nat. gas, and others. • Allocation of overhead was based on time- and floor space demands for individual manufacturing processes (unit processes). As such, an overhead factor (overhead/hr/sqft) was multiplied by the square-footage covered by a particular unit process and divided by the number of parts/hr in order to get the relative overhead intensity/part for that particular unit process. • Overhead for powder coating was directly included in the powder coating unit process (SimaPro). • Powder coating data for both Athens, Alabama, and Grand Rapids, Michigan, operations was based on primary data collected at Steelcase, Grand Rapids, facilities.[7] No specific data was collected at Steelcase, Athens, since powder coating technology there was updated to Grand Rapids standards.

Table 2.3.-1 continued

	• Supplier parts were modeled only with respect to their major material(s) as well as manufacturing process. The actual weight for plastic, aluminum-, and particleboard parts, sourced from suppliers, was calculated from estimated part volumes and material densities. Table 2.3.-2 shows specific material production processes, and related information sources, used for these calculations. • In general, manufacturing scrap as well as packaging was only accounted for with respect to processes executed at Steelcase facilities. However, steel scrap was also assigned to supplier parts (if steel was involved) that were heavier than 1 lb. • Manufacturing scrap/waste generated at Steelcase Grand Rapids facilities was treated as follows: Wood waste was burned at the Genese, Michigan, waste-to-energy facility. Sawdust was used for daily cover (landfill) and roadbed material. Scrap steel was recycled at Padnos Iron & Metals at either their Holland, Michigan, or Grand Rapids, Michigan, facilities. Cardboard, plastics, and other materials were recycled at Recycle America in Grand Rapids, Michigan. Powder coating waste was landfilled at Autumn Hills RDF located near Zealand, Michigan.[8] • The manufacturing waste scenario was supposed to be the same for Steelcase facilities in Grand Rapids, Michigan, and Athens, Alabama. • Lubricants and stamping oils (secondary flows) were allocated on a time basis. That is, depending on the duration of part-related machinery operations and based on a hourly consumption rate. • Airline oils (secondary flows) were allocated on a volume basis. That is, based on a per cycle consumption for part-related machinery operation. • Packaging scrap generated at Steelcase operations (foil-, paper-, and cardboard scrap, as well as packaging scrap related to the delivery of supplier parts) were not accounted for in this model. • Transportation was accounted for only with respect to materials, parts, sub-assemblies, and assemblies heavier than 1 lb and/or for distances equal or greater than 100 miles. • Transportation of supplied parts was accounted for only between the last supplier and a Steelcase facility or end customer. • Forklift operation at Steelcase facilities was modeled only with respect to electricity consumption. Related equipment (battery chargers, etc.) is not accounted for.
Use	• Environmental burdens concerning the use of office furniture products were generally assumed to be negligible compared to their overall life cycle impacts. Possible moving- and cleaning activities during the use phase were minor and did not account for significant environmental impacts. Based on company experience, the average life expectancy for the three office furniture product systems under consideration was 20 years.[9]
End of life	• Since there was no product take back program in place, Steelcase office furniture products were supposed to enter the regular U.S. municipal waste treatment scenario, which distinguished between the four different waste categories 'durable goods', 'non-durable goods', 'containers and packaging', and 'other wastes'. For this study, and due to the nature of the three office furniture products under consideration, product systems were classified as durable goods, while the involved packaging materials were classified as containers and packaging. A standard end-of-life waste treatment scenario was derived from EPA information on municipal waste (MW). Accordingly, the average recycling rates for specific materials stemming from durable goods, and containers and packaging were as reported in Table 2.3.-3. The average treatment for the remaining municipal solid waste (MSW; after separating materials for recycling) in 2001 was as follows: 14.7% of MSW was combusted, 55.7% of MSW was landfilled, and for 29.6% of MSW treatment was unknown.[10]

1 BEES: Building for Environmental and Economic Sustainability; www.bfrl.nist.gov/oae/software/bees.html
2 E-mail note; Denise Van Valkenburg; Steelcase Inc.; Grand Rapids, MI; June 21, 2004
3 www.tva.com/power/powerfacts.htm; www.epa.gov/cleanenergy/egrid/index.htm
4 E-mail note; Kathleen Bolinger; Steelcase Inc.; Grand Rapids, MI; August 14, 2003
5 Meeting note; Sharon Albaugh; Steelcase Inc.; Grand Rapids, MI; August 26, 2003
Steelcase internal engineering data base "Work Manager"
6 Information provided by:
Darryl Long, Lynn Moran; Steelcase Inc.; Athens, AL; April 14, 2004
Dennis Hill; Steelcase Inc.; Grand Rapids, MI; Sept. 23, 2003
7 Primary data was acquired at Steelcase Inc.; Grand Rapids, MI; August 27, 2003
8 E-mail note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; June 18, 2004
9 Meeting note; Wendy Hoerner, Kurt Heidman; Steelcase Inc.; Grand Rapids, MI; June 13, 2003
10 U.S. Environmental Protection Agency; Municipal Solid Waste in the United States; Washington D.C., USA; October 2003

Table 2.3.-2 Data sources of material production processes used for re-calculation purposes (see also Section [3.2.1.])

Production process	SimaPro source	Primary source	Additional source (specific material properties, e.g. density, etc.)	
Plastics[1]				
ABS P, US	Data archive	PWMI report 11 ABS & SAN	BASF worksheet on Terluran	www.basf.de
LDPE film FAL	Franklin USA 98	Franklin USA 98	Alan Mauer; Steelcase Inc.	
LLDPE film FAL	Franklin USA 98	Franklin USA 98	Alan Mauer; Steelcase Inc.	
PA 6 I, US	Idemat 2001	PWMI report 4 PS	BASF worksheet on Ultramid	www.basf.de
PA 6.6 A, US	Industry Data	APME Ecoprofiles	DuPont worksheet on Nylon	www.automotive.dupont.com
PC C, US	Data archive	Chalmers (1991)	MatWeb	www.matweb.com
PE (LDPE) I, US	Idemat 2001	PWMI report 3 PE/PP		
PE expanded I, US	Idemat 2001	PWMI report 3 PE/PP		
PE granulate average B250, US	Buwal 250	Buwall 250 (1997)		
PET bottle grade I, US	Idemat 2001	APME report 8 PE	Univ.of Southern Mississippi	www.psrc.usm.edu/macrog/pet.htm
PMMA beads P, US	Data archive	PWMI report 14 PMMA	Ticona Engineering Polymers	www.ticona.com
Polyester fabric I, US	Idemat 2001	Franklin Assoc. (1993)		
PP caps FAL	Franklin USA 98	Franklin USA 98		
PP injection moulded A, US	Industry Data	APME Ecoprofiles		
PS (EPS) FAL	Franklin USA 98	Franklin USA 98	MatWeb	www.matweb.com
PVC FAL	Franklin USA 98	Franklin USA 98	Solvay S.A.	www.solvinpvc.com
SAN A, US	Industry Data	APME Ecoprofiles	BASF worksheet on Luran	www.basf.de
Laminate		Wilsonart Int.	MatWeb	www.matweb.com
			Richard Conde; Wilsonart Int.	
Metals				
Aluminum			Automotive Handbook[2]	
Steel			Automotive Handbook	
Zamak alloys			Mid America Alloys	www..biganodes.com/html/alloy_specs.htm
Wood				
Particleboard		BEES	Denise van Valkenburg; Steelcase Inc.	
Others				
Argon ETH S, US	ETH-ESU 96	ETH-ESU 96	Air Liquide	www.airliquide.com
CO_2 B250, US	Buwal 250	Buwal 250 (1996)	Air Liquide	www.airliquide.com
Bonderite 3128			Henkel Technologies	www.henkel.com/int_henkel/technologies
Parco cleaner 3140			Henkel Technologies	www.henkel.com/int_henkel/technologies
Parco neutralizer 700			Henkel Technologies	www.henkel.com/int_henkel/technologies
Parcolene 6			Henkel Technologies	www.henkel.com/int_henkel/technologies
Parcolene 99A			Henkel Technologies	www.henkel.com/int_henkel/technologies
Primer 40			Henkel Technologies	www.henkel.com/int_henkel/technologies

Table 2.3.-3 EOL standard scenario[3] and recycling rates		
Waste management strategy	**Target material(s)**	**Rates**
Waste recycling		
EOL ferro scrap, US	Ferro metals	28 %
EOL non-ferro scrap, US	Non-ferro	60 %
EOL non-ferro scrap, US	Coppers	60 %
EOL non-ferro scrap, US	Magnesium	60 %
EOL non-ferro scrap, US	Zincs	60 %
EOL aluminum scrap, US	Aluminum	0 %
EOL glass waste, US	Glass	0 %
EOL PE, US	PE	5.5 %
EOL PET, US	PET	5.5 %
EOL Plastics (excl. PVC), US	Plastics	5.5 %
EOL PP, US	PP	5.5 %
EOL PVC, US	PVC	5.5 %
EOL wood waste output, US	Wood	15 %
EOL cardboard, US	Cardboard	55 %
EOL paper, US	Paper	55 %
Treatment of waste remaining after recycling		
Waste incineration	All	14.7 %
Waste landfill	All	57 %

2.4. Process flow diagrams

For better understanding of the office furniture product systems evaluated, this section shows generic process flow diagrams indicating key product stages (light grey), -material flows (dark grey), and -handling processes (white) for each product system (Fig. 2.4.-1 through 2.4.-3). Although not shown explicitly, in general, material flows and handling processes are associated with one or more types of energy input (electricity, nat. gas, steam, etc.). Arrows between boxes not only represent flows of materials and parts/subassemblies but also stand for related transportation activities. The latter cover the whole range from ocean going vessels to forklift operation within manufacturing facilities. Thin dotted lines indicate material recovery processes at product end-of-life, which partially cycle materials back into industrial processes. These recycling loops should not be taken literally in terms of materials actually feeding back into the manufacture of the very same product system. Rather, they must be considered recycling loops, were EOL materials from one product system most likely get recycled in a different product systems.[4] As shown in the diagrams, no recycled content went into plastic materials for part molding, polyester material for powder coating, and primary metals for electrocoating. All of these processes required virgin material inputs. Actual recycling rates for various materials as applied in this study are shown in Table 2.3.-3. For clarity purposes, packaging materials are not shown in the diagrams. A set of fully elaborated process flow diagrams generated for life cycle modeling in this study can be found as PDF-files in Appendix D.

1 ABS = Acrylnitril-Butadian-Styrol
LDPE = Low Density Polyethylene
LLDPE = Linear Low Density Polyethylene
PA = Polyamide
PC = Polycarbonate
PE = Polyethylene
PET = Plyethylene-Terepthalate
PMMA = Polymethylmethacrylate
PP = Polypropylene
PVC = Polyvinyl-Chloride
SAN = Styrol-Acrylnitril-Copolymere

2 Bauer, Horst; Automotive Handbook; Robert Bosch GmbH; Stuttgart, Germany; 1996

3 Municipal Solid Waste in the United States; U.S. Environmental Protection Agency; Washington D.C., USA; October 2001; p. 9

4 ISO 14041 standard; International Organization for Standardization; Geneva, Switzerland; 1998; p. 12

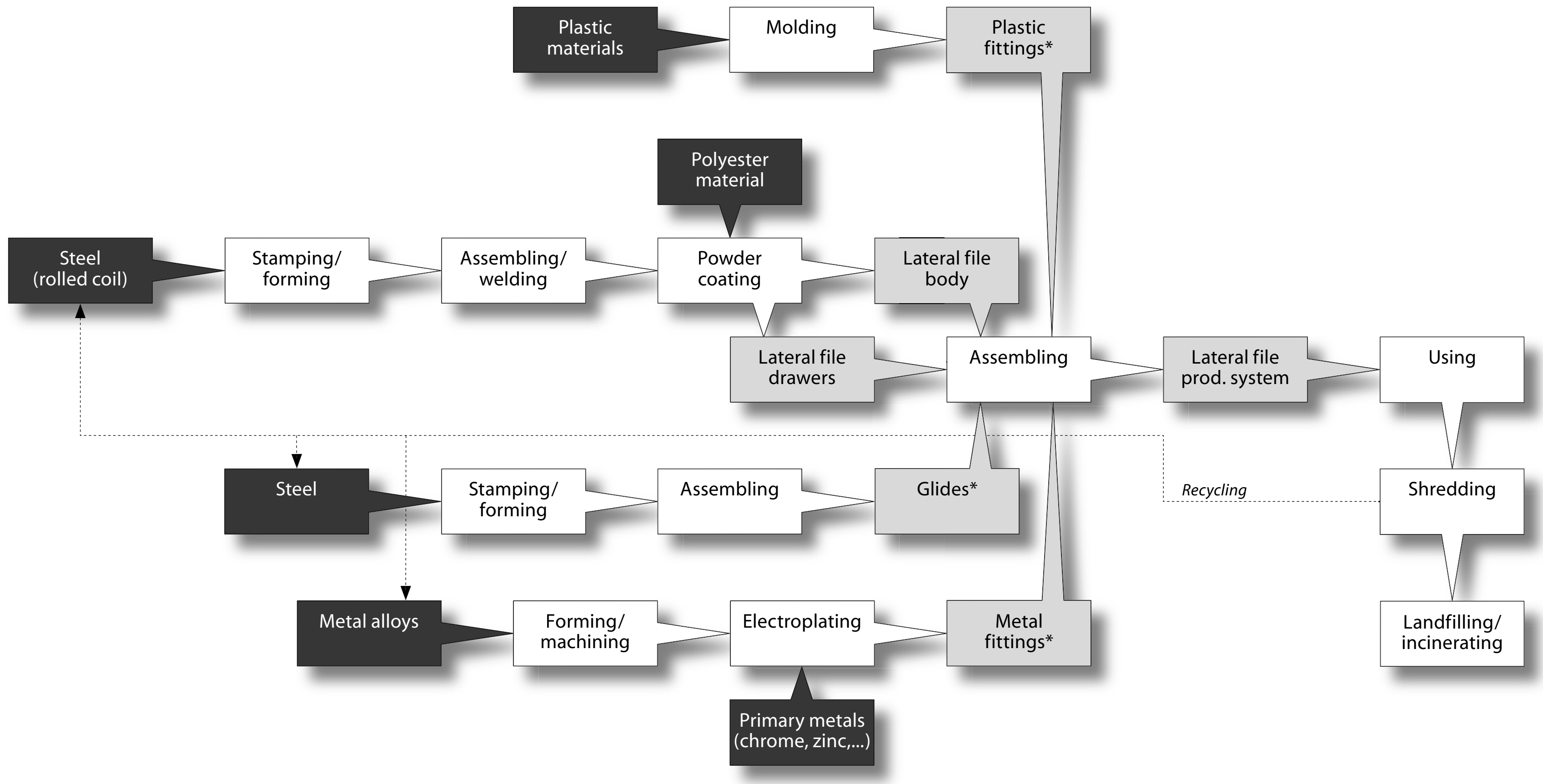


Fig. 2.4.-1
Process flow diagram of lateral file product system. The white boxes are activities, the light grey boxes are parts and assemblies, and the dark grey boxes are material inputs.

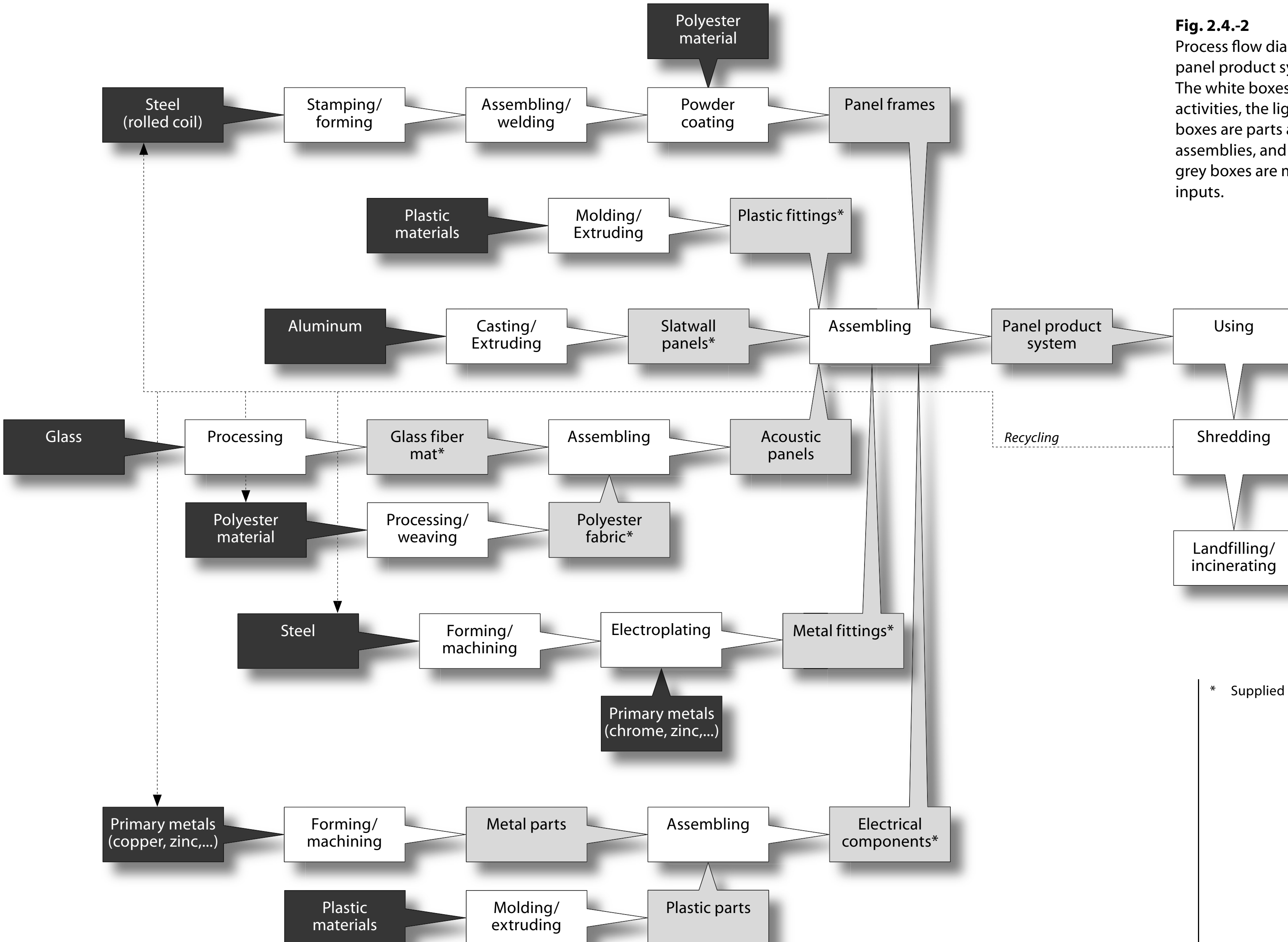


Fig. 2.4.-2
Process flow diagram of panel product system. The white boxes are activities, the light grey boxes are parts and assemblies, and the dark grey boxes are material inputs.

* Supplied parts

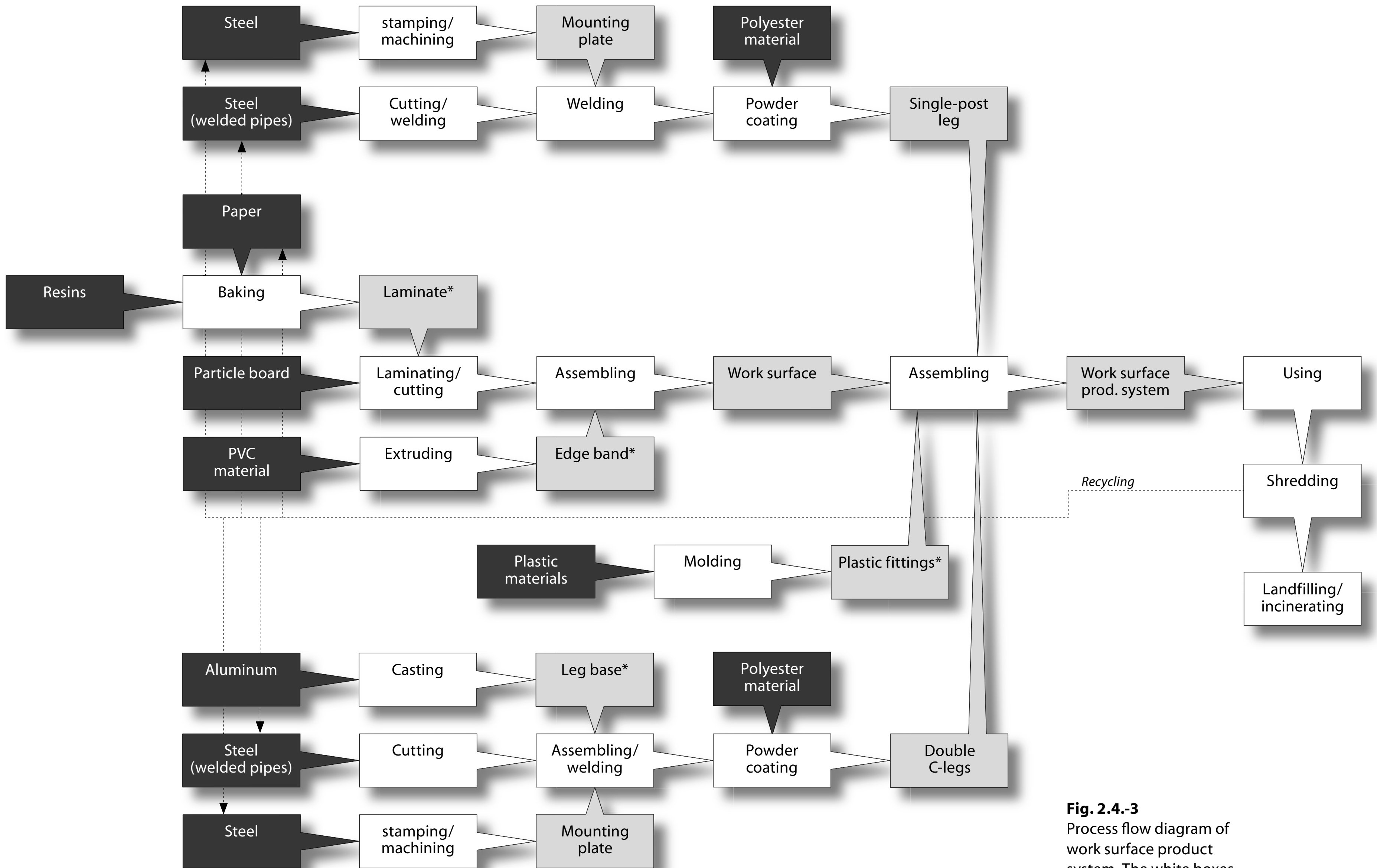


Fig. 2.4.-3
Process flow diagram of work surface product system. The white boxes are activities, the light grey boxes are parts and assemblies, and the dark grey boxes are material inputs.

* Supplied parts

3. Data collection and analysis

This chapter describes the general procedure for conducting this research in terms of how the fundamental data was collected, how this data was analyzed and assessed, and how results were derived from the assessment. It also introduces specifics for Steelcase manufacturing strategies and equipment.

3.1. Methodology

This study followed the general framework for conducting a life cycle assessment (LCA) as defined in the ISO 14040 standard.[1] In addition to data collection, the framework comprises four major steps, which are 'goal and scope definition', 'life cycle inventory analysis', 'life cycle impact assessment', and 'life cycle interpretation'. Appendix A shows a diagram of the entire process carried out along a generic product system life cycle.

According to ISO, a life cycle inventory analysis records the use of resources as well as releases to air, water, and land associated with a certain product system. These data constitute the input to life cycle impact assessment (LCIA).

The life cycle impact assessment phase of LCA evaluates the significance of potential environmental impacts. This involves associating inventory data with specific environmental impacts usually defined as impact categories. Environmental impact categories and related pollutants are explained in greater detail in Section [3.3.]. In order to best represent spatial and temporal conditions for the U.S., the TRACI framework was applied regarding impact assessment for this study.[2] That is, environmental impacts associated with releases of certain pollutants were evaluated specifically with respect to social, biological, and geographical circumstances found in the U.S.

In terms of data collected, information on product composition, material usage, manufacturing practices, and manufacturing facilities was obtained directly at Steelcase throughout its Grand Rapids, Michigan, and Athens, Alabama, facilities. Data were retrieved from, first, Steelcase databases already in place such as Spec-Guides (product specifications), Workmanager (engineering workflow database), and SAP R3 (integrated business solutions system), second, individual interviews led with staff members across various engineering and manufacturing departments, and third, personal observations. The data collected include types of parts and assemblies, manufacturing locations, primary and ancillary materials, manufacturing processes, machinery, floor space occupied by machinery, utilities (energy, water, air, etc.), manufacturing scrap, transportation efforts, packaging, and others. Table 3.1.-1 shows a full list of items encompassed by the data collection – related spreadsheets can be found as PDF-files in Appendix D.

In the end, Steelcase-specific data collection facilitated a accurate representation of Steelcase operations. From there, process flow models were developed, using the SimaPro LCA software[3], for every office furniture product system, replicating material-, energy-, and waste flows coupled with flows of parts, subassemblies and assemblies along the entire product system life cycles. Material unit processes and related environmental data for the material production phase were taken from Franklin-, Idemat-, and Buwal databases as shown in detail in Table 3.1.-2. In order to better represent U.S. conditions, however, some original raw material-, energy- and transportation data elements embedded in Idemat- and Buwal datasets were substituted with comparable data from Franklin Associates. This is indicated through the suffix 'US' at the end of adapted dataset names.

For the manufacturing phase, the majority of unit processes were generated specifically from the data collected at Steelcase facilities. For supplier parts, again, more generic unit processes were modeled using databases mentioned above (see Table 3.1.-2).

The use phase was not modeled as described in Chapter [2.1.]. With regard to the retirement phase, an end-of-life scenario was created based on general data from the U.S. Environmental Protection Agency (EPA) on managing municipal waste.[4]

3.2. Life cycle inventory analysis (LCI)

The complete life cycle data for each office furniture product system can be viewed as PDF-files in Appendix D. Since material provision-, manufacturing-, and waste management strategies were highly common to all three product systems, descriptions throughout Sections [3.2.1], [3.2.2], and [3.2.3] do not distinguish between product systems.

3.2.1. Material provision stage

Steel

Steel in this study is categorized by hot-rolled coil (HRC), cold-rolled coil (CRC), steel section (SS), and welded pipes (WP) purchased from different suppliers. No environmental requirements were specified by Steelcase for steel sourcing.[5] As a consequence, regarding this study, environmental data for steel was based on world average data provided by the International Iron and Steel Institute (IISI).[6] Hot- and cold-rolled steel was applied in sheet metal parts for the lateral file- and panel

Table 3.1.-1 Items surveyed during life cycle data collection at Steelcase facilities

Item
Unit
Steelcase unit #
Steelcase unit name
Kind and amount of unit
Work center # (group of machinery/assets)
Asset # (single machinery)
Asset description
Space occupied by asset(s)
Production
Activity performed
Location of activity (Steelcase vs. supplier)
Energy (for activity)
Electricity
Compressed air
Natural gas
Primary flows (stay in product)
In-flows/primary materials
Origin/supplier of in-flows
Secondary flows (do not stay in product)
Water in/out
In-flows/ancillary materials
Origin/supplier of in-flows
Out-flows/ancillary materials
Destination of out-flows
Transportation
Means of transportation
Distance shipped
Packaging
Type and amount of packaging material(s)

1 ISO 14041 standard; International Organization for Standardization; Geneva, Switzerland; 1998; p. 12
2 Bare, Jane C.; TRACI (The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts); U.S. EPA; Cincinnati, OH; 2003
3 SimaPro Software, Version 5.1; PRé Consultants; Amersfoort; The Netherlands; 2002
4 Municipal Solid Waste in the United States; U.S. Environmental Protection Agency; Washington D.C., USA; October 2003
5 E-mail note; Mick Rakowski; Steelcase Inc.; Grand Rapids, MI; June 7, 2004
6 Scott Chubbs; International Iron and Steel Institute; Brussels, Belgium; July 22, 2004

Table 3.1.-2 Inventory data sources used for material production-, manufacturing-, and energy generation processes in this study

Process	SimaPro source	Primary source
Ferro metal production		
50CrV4 I, US	Idemat 2001	SPIN Iron and Steel (1992)
IISI, cold rolled coil	IISI 2004	IISI 2004
IISI, hot rolled coil	IISI 2004	IISI 2004
IISI, steel section, EAF route	IISI 2004	IISI 2004
IISI, welded pipes	IISI 2004	IISI 2004
Iron ore, US	Data archive	Bergh & Jurgens (1990)
Iron, US	Data archive	Bergh & Jurgens (1990)
Sinter, pellet, US	Data archive	Bergh & Jurgens (1990)
Non-ferro metal production		
Chromium I, US	Idemat 2001	Metals and Minerals (1999)
Copper I, US	Idemat 2001	Metals and Minerals (1999)
Lead I, US	Idemat 2001	Metals and Minerals (1999)
Magnesium I, US	Idemat 2001	Metals and Minerals (1999)
Manganese I, US	Idemat 2001	Metals and Minerals (1999)
Nickel I, US	Idemat 2001	Metals and Minerals (1999)
Scrap (copper) I, US	Idemat 2001	Energiekentallen 2 (1992
Scrap (Mg) I, US	Idemat 2001	Energiekentallen 2 (1992)
Scrap (Pb) I, US	Idemat 2001	Energiekentallen 2 (1992)
Scrap (Sn) I, US	Idemat 2001	Energiekentallen 2 (1992
Tin I, US	Idemat 2001	Metals and Minerals (1999)
Titanium I, US	Idemat 2001	Metals and Minerals (1999)
Vanadium I, US	Idemat 2001	Metals and Minerals (1999)
Zinc I, US	Idemat 2001	Metals and Minerals (1999)
ZnCuTi I, US	Idemat 2001	Metals and Minerals (1999)
Aluminum production		
AlCuMg1 (2017) I, US	Idemat 2001	Idemat 2001
AlCuMgPb (2011) I, US	Idemat 2001	Idemat 2001
Aluminium 25% rec. B250, US	Buwal 250	Buwal 250 (1997)
Aluminium ingots I, US	Idemat 2001	EAA report 1996
Aluminium rec. I, US	Idemat 2001	World resources 95-97
Plastic production		
ABS P, US	Data archive	PWMI report 11 ABS & SAN
LDPE film FAL	Franklin USA 98	Franklin USA 98
LLDPE film FAL	Franklin USA 98	Franklin USA 98
PA 6 I, US	Idemat 2001	PWMI report 4 PS
PA 6.6 A, US	Industry Data	APME Ecoprofiles
PC C, US	Data archive	Chalmers (1991)

Table 3.1.-2 continued

PE (LDPE) I, US	Idemat 2001	PWMI report 3 PE/PP
PE expanded I, US	Idemat 2001	PWMI report 3 PE/PP
PE granulate average B250, US	Buwal 250	Buwall 250 (1997)
PET bottle grade I, US	Idemat 2001	APME report 8 PE
PMMA beads P, US	Data archive	PWMI report 14 PMMA
Polyester fabric I, US	Idemat 2001	Franklin Assoc. (1993)
PP caps FAL	Franklin USA 98	Franklin USA 98
PP injection moulded A, US	Industry Data	APME Ecoprofiles
PS (EPS) FAL	Franklin USA 98	Franklin USA 98
PVC FAL	Franklin USA 98	Franklin USA 98
SAN A, US	Industry Data	APME Ecoprofiles
Chemical production		
Ammonia B250, US	Buwal 250	Buwall 250 (1996)
Argon ETH S, US	ETH-ESU 96 System	ETH-ESU 96 System
Carbon black I, US	Idemat 2001	Emissieregistratie (1993)
Chemicals inorganic ETH S, US	ETH-ESU 96 System	ETH-ESU 96 System
Chemicals organic ETH S, US	ETH-ESU 96 System	ETH-ESU 96 System
CO2 B250, US	Buwal 250	Buwall 250 (1996)
Formaldehyde I, US	Idemat 2001	Emissieregistratie (1992)
HF ETH S, US	ETH-ESU 96 System	ETH-ESU 96 System
Melamine I, US	Idemat 2001	Emissieregistratie (1993)
MF I, US	Idemat 2001	Emissieregistratie (1992)
NaOH (100%), US	Buwal 250	Buwall 250 (1996)
Oxygen bj, US	Data archive	Bergh & Jurgens (1990)
PF (resin) I, US	Idemat 2001	Emissieregistratie (1992)
Phenol I, US	Idemat 2001	SPIN Phenol (1993)
Phosphoric acid ETH S, US	ETH-ESU 96 System	ETH-ESU 96 System
Phosphoric acid I, US	Idemat 2001	Emissieregistratie (1990)
Sulfuric acid I, US	Idemat 2001	Emissieregistratie (1990)
Wood production		
Particleboard	BEES	BEES plywood
Yellow pine I, US	Idemat 2001	Holzatlas 1998
Production, others		
Coke S, US	Data archive	SPIN Cokes (1992)
Corrugated cardboard FAL	Franklin USA 98	Franklin USA 98
Glass, fiber- or -wool, US	Data archive	SPIN Glass (1992)
Kerosene I, US	Idemat 2001	Emissieregistratie (1992)
Lime bj, US	Data archive	Bergh & Jurgens (1990)
Lime stone bj, US	Data archive	Bergh & Jurgens (1990)
Paper kraft bleached FAL	Franklin USA 98	Franklin USA 98

Table 3.1.-2 continued

Pulp for cardboard B, US	Data archive	Buwal 132 (1990)
Silicon I, US	Idemat 2001	Metals and Minerals (1999)
Stoneware I, US	Idemat 2001	SPIN Ceramics 2 (1992)
Energy generation		
Crude oil I, US	Idemat 2001	PWMI report 2 Olefins
Electricity avg. kWh USA	Franklin USA 98	Franklin USA 98
Electricity from coal FAL	Franklin USA 98	Franklin USA 98
Electricity from DFO FAL	Franklin USA 98	Franklin USA 98
Electricity from nat. gas FAL	Franklin USA 98	Franklin USA 98
Electricity from RFO FAL	Franklin USA 98	Franklin USA 98
Electricity from uranium FAL	Franklin USA 98	Franklin USA 98
Electricity hydropower FAL	Franklin USA 98	Franklin USA 98
Energy US I	Idemat 2001	World resources 95-97
Nat. gas into electr. boilers	Franklin USA 98	Franklin USA 98
Refinery products (avg) I, US	Idemat 2001	PWMI report 2 Olefins
RFO into electricity boilers	Franklin USA 98	Franklin USA 98
Steam (refinery process) P, SC	Data archive	PWMI report 2 Olefins
Uranium in electricity boilers	Franklin USA 98	Franklin USA 98
Manufacturing processes		
Cast work, non-ferro, US	Data archive	SPIN Non-ferro (1992)
Chain sawing I, US	Idemat 2001	Statistical yearbook (1993)
Cold transforming steel, US	Data archive	Kemna 1 (1981)
Electroplating Chrome I, US	Idemat 2001	SPIN Galvanic treatm. (1992)
Electroplating Nickel I, US	Idemat 2001	SPIN Galvanic treatm. (1992)
Extrusion I, US	Idemat 2001	APME report 10 Conversion
Extrusion PVC I, US	Idemat 2001	APME report 10 Conversion
Foam blowing PS I, US	Buwall 250	Buwall 250 (1996)
Foil extrusion, US	Data archive	Kemna 1 (1981)
Injection moulding, US	Data archive	Kemna 1 (1981)
Machining aluminium, US	Data archive	Kemna 1 (1981)
Machining steel, US	Data archive	Kemna 1 (1981)
Phosphating (Fe s) I, US	Idemat 2001	SPIN Phosphating (1994)
Rolling brass I, US	Idemat 2001	SPIN Non-ferro wals (1992)
Zinc coating S, US	ETH-ESU 96 System	ETH-ESU 96 System

product system. Welded pipes were used for manufacturing work surface legs. Smaller parts (e. g. fittings, etc.) were produced from steel section. Steel materials were chosen based on information retrieved from the Steelcase Workmanager[1] database.

Aluminum

Three different types of aluminum were used for the office furniture product systems: aluminum containing 25% recycled material from BUWAL database (Aluminum 25% rec. B250, US), AlCuMg1 from Idemat database (AlCuMg1 (2017) I, US), and AlCuMgPb also from Idemat database (AlCuMgPb (2011) I, US). AlCuMg1 (2017) I, US and AlCuMgPb (2011) I, US both contained 15% recycled- and 85% virgin material. Aluminum materials were selected based on information retrieved from the Steelcase Workmanager database (see Table 3.2.1.-1).

Table 3.2.1.-1 Aluminum used in parts

Part (Ref.#)	**Aluminum type**
Base-answer, c-leg (803013100)	AlCuMg1 (2017) I, US
Barrel-lock (877104101)	AlCuMgPb (2011) I, US
Spacer-ring (877104118)	AlCuMgPb (2011) I, US
Rail-top, slatwall (803200174)	Al 25% rec. B250, US
Rail-bottom, slatwall (803200184)	Al 25% rec. B250, US
Rail, middle, slatwall (803200237)	Al 25% rec. B250, US

Plastics

As Table 3.1.-2 shows, various plastic materials were applied in the office furniture product systems: Acrylnitril-Butadien-Styrol (ABS), Polyamide 6 and 6.6 (PA), Polycarbonate (PC), Polyethylene (PE), Polyethylene-Foam (PE-F), Polyethylene-Terepthalate (PET), Polymethylmethacrylate (PMMA), Polypropylene (PP),

1 Workmanager – Internal Steelcase material- and workflow engineering database

Polystyrene (PS), Polyvinyl-Chloride (PVC), and Styrol-Acrylnitril-Copolymere (SAN). Unit processes used for modeling the manufacture of plastic materials are stated in Table 3.1.-2. Concerning the polyester fabric applied in the panel product system, the unit process 'Polyester fabric I, US' from Idemat database was employed. Due to lack of information, polyester-thin-film powder used in powder coating processes both at Grand Rapids, Michigan, and Athens, Alabama, facilities was presumed to be derived directly from the 'PET bottle grade I, US' unit process. As such, no additional manufacturing processes for thin-film powder were accounted for. Product weights for smaller parts, not fully specified in the Steelcase Workmanager database, were calculated based on estimated part volume and material density information obtained from additional sources reported in Table 2.3.-1.

Wood

Production of the office furniture product systems required two types of wood. Yellow pine was used in wood skids for transportation purposes and particleboard constituted nearly 50% of total weight for the work surface product system. Respective unit processes were 'Yellow pine I, US' from Idemat database and 'Particleboard, US' derived from BEES[1] data on plywood. Data on material density and transportation needs for particleboard were provided by a wood products manufacturer.[2] According to Steelcase, the particleboard used complied with HUD emission standards[3], however, it was not formaldehyde free.[4]

Paper and cardboard

Paper was used in the office furniture product systems mainly as kraft bleached paper regarding the production of front- and backer laminates for the work surface product system.[5] Minor amounts of paper went into product labeling. Front- and backer laminates (including manufacturing waste) accounted for 1.6 kg in paper use, and thus for nearly 100% of the total kraft bleached paper demand across all product systems. Laminate production is discussed in greater detail below. The unit process applied for paper production in this model was 'Kraft bleached FAL' from Franklin Associates.

Cardboard was employed solely as packaging material to protect the finished product systems during transportation to customers. For the worksurface- and panel product systems about 7 kg of cardboard was used. According to the life cycle data collected, there was no cardboard involved in the lateral file product system. The respective unit process for cardboard manufacturing was 'Corrugated cardboard FAL' from Franklin Associates.

Laminates

Laminates utilized for the work surface product system consisted of a multiple layer of kraft bleached paper and phenolic- and melamine resins. During the laminate manufacturing process, heat and pressure was applied to compress and cure the composite. General data on laminate for this study was compiled from Wilsonart International for the front laminate and L&G Industrial for the backer laminate. Due to confidentiality reasons, however, no information could be attained regarding specific material compositions and energy usage. As a result, material compositions were assumed to be 33% paper, 33% phenolic resin, and 33% melamine resin for the front laminate, and 50% paper and 50% phenolic resin for the backer laminate. Energy consumption during the laminate manufacturing process was not accounted for.

With respect to phenolic- and melamine resins the unit processes 'PF (resin) I, US' and 'MF I, US' from Idemat database were applied. According to these, phenolic- and melamine resins incorporate about 34% and 30% formaldehyde respectively.

3.2.2. Steelcase manufacturing stage

Electricity

Electricity was modeled specifically for each Steelcase manufacturing site studied. As such, Grand Rapids, Michigan, facilities were supplied electricity from Consumers Energy Corporation utility system (CEC), whereas Athens, Alabama, facilities were supplied electricity from Tennessee Valley Authority utility system (TVA). Table 3.2.2.-1 shows the generation mix for both utility systems according to eGRID.[6]

Table 3.2.2.-1 Electricity generation mix

Source	CEC	TVA
Electricity from coal	73 %	65 %
Electricity from DFO	2 %	0 %
Electricity from nat. gas	2 %	0 %
Electricity from uranium	23 %	29 %
Electricity hydropower	0 %	6 %

Overhead

Overhead data comprised electricity usage for general facility operations such as lighting and air make-up units on top of plant roofs. Overhead data also included gas-, steam-, and water consumption for heating- and sanitary purposes. No steam was produced at Steelcase, Athens, facilities.[7] Overhead consumption was allocated on a unit process basis already described in Table 2.3.-1 in Section [2.3.].

For overhead consumption at Steelcase Grand Rapids, Michigan, facilities, Kentwood-West operations were taken as a reference. Kentwood-West facilities occupied 770,000 sqf in floors pace, operated 1,440 light fixtures, each consuming 480 watts of electrical power, and ran 18 air make-up units at an electrical power rating of 30 kW each. Steelcase facilities in Athens, Alabama, used 850,000 sqf in floors pace and operated 1687 light fixtures, each consuming 400 Watts of electrical power. Also, Athens ran 68 light fixtures, each consuming 1,5 kW of electrical power, as well as 17 air make-up units at an electrical power rating of 16 kW each. Lighting- and air make-up units for both Grand Rapids- and Athens facilities were practically operated 24 hours, 7 days a week.[8]

Natural gas usage for Kentwood-West, Michigan, and Athens, Alabama, operations was 21,140,000 cft[9] (2002) and 760,900 cft (2003) respectively (including powder coating processes). Total use of electricity for Kentwood-West, Michigan, and Athens, Alabama, facilities was 13,085,000 kWh (2002) and 16,970,000 kWh respectively (including machinery). Steam- and water consumption was 29,642,000 lb and 321,100 gal for Kentwood-West, Michigan, facilities and 0 lb and 331,360 gal for Athens, Alabama, facilities (Steam was not generated from nat. gas).[10]

Compressed air

Compressed air was provided for various manufacturing purposes both at Grand Rapids, Michigan and Athens, Alabama, facilities. With 985,700,000 cft per year (2002), a total number for compressed air consumption was only available for Kentwood-West, Michigan, operations. Actual amounts of compressed air used for each product system were allocated on a unit process basis. That is, general flows of compressed air (cfm)[11] were identified

1 BEES – Building for Environmental and Economic Sustainability; www.bfrl.nist.gov/oae/software/bees.html
2 E-mail note; Denise Van Valkenburg; Steelcase Inc.; Grand Rapids, MI; June 23, 2004
3 U.S. Department of Housing and Urban Development; Washington D. C., USA; Feb. 27, 2005; www.hudclips.org: Directive Number: 3280.308 – "Particleboard materials shall not emit formaldehyde in excess of 0.3 ppm as measured by the air chamber test specified in Sec. 3280.406."
Directive Number: 3280.406 – Air chamber test method for certification and qualification of formaldehyde emission levels
4 E-mail note; Denise Van Valkenburg; Steelcase Inc.; Grand Rapids, MI; July 1, 2004
5 E-mail note; Richard Conde; Wilsonart International; Temple, TX; July 20, 2004
6 Data for electricity generation were derived from www.epa.gov/airmarkets/egrid/index.htm
7 E-mail note; Lynn Moran; Steelcase Inc.; Athens, AL; July 6, 2004
8 E-mail note; Dennis Hill; Steelcase Inc.; Grand Rapids, MI; June 8, 2004
9 cft = cubic feet
10 General utility information was provided by Dennis Hill for Kentwood-West, Michigan, operations and Lynn Moran and Darryl Long for Athens, Alabama, operations
11 cfm = cubic feet/minute

based on the diameter of air pipes running into certain manufacturing equipment. Table 3.2.2.-2 shows compressed air flows in relation to pipe size. From there, air flows were multiplied by the fraction of time needed

Table 3.2.2.-2 Air pipe dimensioning[1]

Volume of air transmitted (cfm)	Pipe diameter (inches)
30 - 60	1
60 - 100	1
100 - 200	1 ¼
200 - 500	2
500 - 1000	2 ½
1000 - 2000	2 ½
2000 - 4000	3 ½

to perform the specific unit process in order to gain the actual amount of compressed air associated with a unit process. For particular pieces of equipment, such as mechanical- and hydraulic presses, as well as spot-welders, however, compressed air consumption was given as a cost factor per operation cycle.[2] For those instances, the volume of compressed air used per unit process could be re-calculated based on compressed air cost.[3] Table 3.2.2.-3 illustrates consumption factors for various machinery.

Cooling water

Hydraulic presses, welding-, and laser cutting equipment needed to be cooled during operation. As a consequence, cooling water systems were installed at both Grand Rapids, Michigan, and Athens, Alabama, facilities. For feasibility purposes, data collected at Kentwood-West, Michigan, ventures were also used for evaluating Athens, Alabama, facilities. Cooling water demand for Kentwood-West, Michigan, facilities was 800 gal/min, which translated into 480,000 gal during a 10 hr work day. However, this was water circulating throughout a closed system comprising a cooling tower, various electrical pumps, and to-be-cooled machinery. Only 0.5% of cooling water had to be replenished by fresh water due to evaporation losses in the cooling tower. As such, the fresh water demand for the Kentwood-West, Michigan, cooling water system was about 220 gal/hr. Water use for cooling purposes was either allocated on a per cycle basis regarding unit processes performed on to-be-cooled manufacturing equipment, or on a time and power related basis. Similar to compressed air, the former was done by re-calculating water usage via cooling water cost (e. g. spot welders).[4] The latter was done based on operations experience showing that approximately 1.35 gal/min of cooling water is required for every kW in installed equipment power (e. g. hydraulic presses).[5] Consumption factors for particular manufacturing equipment are shown in Table 3.2.2.-3.

Average electrical power consumption for pumps and a tower fan for the cooling water system totaled in 44 kW. This took into account that parts of the system only ran temporarily depending on cooling water temperature.

Welding

Most steel components for the product systems under consideration were assembled through welding processes. Welding processes mainly comprised spot-, projection-, and MIG (Gas Metal Arc) welding. Consumption factors for those processes are shown in Table 3.2.2.-3. However, spot welders additionally used up copper tips, whereas MIG welders consumed welding wire as well as welding gas to shelter the weld from ambient air in order to avoid oxidation. Welding tips weighed about

Table 3.2.2.-3 Electricity-, air-, and cooling water consumption for selected manufacturing equipment[2,8]

Equipment	Consumption of *Electricity*	*Compr. air*	*Cooling water*
Spot welder (foot stamper)	0.095 kWh/weld	N/A	0.25 gal/weld
Projection welder	0.095 kWh/weld	5 cf/weld	0.25 gal/weld
MIG welder	0.079 kWh/inch	0.95 cf/inch	0.5 gal/inch
Mech. press, 175 tons, 135 kW (small)	0.0095 kWh/cycle	0.6 cf/cycle	N/A
Mech. press, 250 tons, 150 kW (medium)	0.014 kWh/cycle	1.25 cf/cycle	N/A
Hydr. press, 250 tons, 150 kW (medium)	0.014 kWh/cycle	1.25 cf/cycle	200 gal/min
Mech. press, 400 tons, 165 kW (large)	0.019 kWh/cycle	2.5 cf/cycle	N/A
Hydr. press, 400 tons, 165 kW (large)	0.019 kWh/cycle	2.5 cf/cycle	220 gal/min
Roller press	0.42 kWh/min	25 cf/min	N/A
CNC laser cutter (steel)	0.45 kWh/min	25 cf/min	N/A
CNC router (wood)	0.33 kWh/min	25 cf/min	N/A
Hot-melt station (fabric)	0.31 kWh/min	35 cf/min	N/A
Hot-laminating press (wood)	0.53 kWh/min	17 cf/min	N/A
Powder coating line	10.7 kWh/min	147 cf/min	N/A
Conveyor band (per motor)	0.007 kWh/min	N/A	N/A
Stretch foiler (packaging)	0.083 kWh/min	5 cf/min	N/A
Hand tools	0.007 kWh/min	N/A	N/A

3 ounces and took an average of 3000 spot welds to wear off.[6] Welding gas consisted of 50% Argon and 50% CO_2 and was used at a rate of 0.05 cf per inch of welded material.[5,6] Welding wire consisted of carbon, manganese, silicon, phosphor, sulfur and copper and was consumed at a rate of 0.0005 lb per inch of welded material.[7] Welding processes were allocated on a cycle basis for spot- and projection welders and on a length basis for MIG welders. That is, the length of the actual weld defined the amount of energy- and welding materials assigned to MIG welding processes.

Machinery

Besides welding, various other types of machinery were involved in manufacturing the lateral file-, panel-, and work surface product systems. Many of them were related to cutting-, blanking-, stamping-, forming-, trimming-, sanding-, and other processes related to steel-, wood-, and fiber materials. Metal casting-, galvanic surface coating-, plastic extrusion-, and plastic molding processes were performed by suppliers exclusively. Table 3.2.2.-3 shows the main types of Steelcase manufacturing equipment involved in this study as well as related consumption factors.

1 Steelcase instructive guide lines for air system configuration provided by William Ryszka; Steelcase Inc.; Grand Rapids, MI; Aug. 14, 2003
2 Meeting notes; Dennis Hill; Steelcase Inc.; Grand Rapids, MI; Aug. 26, 2003
3 Dennis Hill; Steelcase Inc.; Grand Rapids, MI; Aug. 26, 2003: Cost for compressed air at Kentwood-West, MI, operations were $0.22/1,000 cf
4 Dennis Hill; Steelcase Inc.; Grand Rapids, MI; Aug. 26, 2003: Cost for fresh water (incl. sewage cost) at Kentwood-West, MI, operations were $2.96/100 cf (= 748 gal)
5 Meeting note; William Ryszka; Steelcase Inc.; Grand Rapids, MI; Aug. 14, 2003
6 Meeting note; Anthony Lafata; Steelcase Inc.; Grand Rapids, MI; date missing
7 E-mail note; Michael Wind; Steelcase Inc.; Grand Rapids, MI; June 10, 2004
Hobart Brothers; Troy, OH; BR-3 welding wire series
8 E-mail note; Tom Nicols; Steelcase Inc.; Grand Rapids, MI; Aug 13, 2003

With respect to vertically operating steel presses, two different types, mechanical and hydraulic, were applied of which the former were small and medium models and the latter medium and large models. Hydraulic presses included various additional equipment like feeders, straighteners, and derailleurs. Unlike mechanical presses, hydraulic presses required cooling (see also Section on 'cooling water' above). Roller presses were a different kind of steel forming technology, where steel profiles were shaped by passing steel sheets through a horizontal array of motor-driven rollers. Roller presses demonstrated high throughput rates.

CNC (Computer Numerical Control) technologies were applied for punching certain steel panels of the lateral file product system and for cutting the particleboard desktop.

Hot-melt equipment was employed for assembling fiber mats and polyester fabric to acoustic panels used in the panel product system and for laminating particleboard for the work surface product system.

Conveyor lines used for product system manufacture studied were mostly related to manual assembling processes. Depending on length, conveyors harnessed up to 14 motors, each consuming 400 Watts in electrical power.

Also with respect to manual tasks, various electrical hand tools (drills, staplers, grinders, etc.) were used during assembling processes within and beyond Steelcase facilities. For feasibility purposes hand tool power consumption was generally rated at 500 Watts.

Comprehensive and detailed information on the allocation of Steelcase machinery to product system related manufacturing processes is documented in the data collection spreadsheets shown as PDF-files in Appendix D.

Powder coating

Regarding the product systems under investigation, steel parts and components manufactured at both Steelcase Grand Rapids, Michigan, and Athens, Alabama, facilities, were painted using state of the art powder coating technology. Powder coating lines were major operations within Steelcase facilities and physically separated from other manufacturing activities mainly for paint quality insurance- as well as particulate containment purposes. Overall, powder coating lines consisted of three major stages: initial cleansing- and degreasing processes, subsequent powder spray booths, and final cure ovens. Powder coating and related energy and material usage was allocated to product systems on a sqf basis[1] – that is, sqf of powder coating necessary for painting specific parts. Powder coating information valid for all Steelcase sites was retrieved from a powder coating line within the Steelcase Grand Rapids, Michigan, facilities.[2] On average, powder coating operations ran 9 hrs/day, 250 days/year, and coated 32,000 sqf of product surface daily. Various chemicals were applied during the cleansing- and degreasing stage as documented in Table 2.3.-2 ('Henkel' products in category 'others'). Daily consumption of electricity- and compressed air for powder coating processes was 5763 kWh and 79200 cf respectively. About 1160 cf of natural gas were required per day to operate curing ovens (equal to 350 kWh thermal energy). Paint powder (thin-film powder) was applied to product surfaces as dry material and via spray-guns. In order to increase powder efficiency, powder coating equipment as well as to be painted products were electrostatically charged, which enhanced thin-film powder attachment to material surfaces. However, based on experience, powder utilization rates did not exceed 60%, which is, at least 40% of

Table 3.2.2.-4 Oil and lubricant consumption for selected manufacturing equipment

Equipment	Consumption of *Lubricants*	*Stamping oil*	*Air line oil*
Mech. press, 175 tons, 135 kW (small)	0.012 lb/hr	N/A	0.28E-6 gal/cycle
Mech. press, 250 tons, 150 kW (medium)	0.016 lb/hr	N/A	0.58E-6 gal/cycle
Hydr. press, 250 tons, 150 kW (medium)	0.016 lb/hr	0.17 lb/hr	0.58E-6 gal/cycle
Mech. press, 400 tons, 165 kW (large)	0.023 lb/hr	0.17 lb/hr	1.15E-6 gal/cycle
Hydr. press, 400 tons, 165 kW (large)	0.023 lb/hr	0.17 lb/hr	1.15E-6 gal/cycle
Roller press	0.012 lb/hr	0.17 lb/hr	1.15E-5 gal/cycle

powder had to be discharged as overspray solid waste, particularly due to inseparable color mixing.

Oils and lubricants

Lubricants and oils were tracked for mechanical, hydraulic, and roller presses involved in the manufacturing of the lateral file-, panel-, and work surface product system. Both lubricants and oils were assigned to blanking, forming, cutting, and other processes based on unit process duration and daily consumption rates of ancillary materials. Stamping oils were sprayed onto steel materials before pressing processes to achieve smoother bending, whereas air line oils were added to compressed air systems for continuous machine oiling. Lubricants were applied during ordinary equipment maintenance.[3] Consumption rates for oils and lubricants with respect to different machinery are shown in Table 3.2.2.-4.

Manufacturing scrap/waste

For both, mechanical- and hydraulic presses, as well as CNC equipment steel scrap was assigned to manufacturing processes at rates of 5%, 9%, and 12% of the original material weight depending on part size and shape.[4] Steel scrap for roller presses was insignificant due to the nature of rolling processes. In general steel manufacturing scrap at Steelcase was fully recycled.

Wood manufacturing waste, in particular particleboard, was incinerated with energy recovery. Cardboard and plastic waste, which accrued throughout Steelcase Grand Rapids, Michigan, and Athens, Alabama, facilities was mainly related to packaging materials for materials

Table 3.2.2.-5 Manufacturing scrap/waste management applied at Steelcase Grand Rapids, Michigan, facilities[5]

Scrap/waste type	Treatment
Steel/metals	Recycling (Padnos Iron & Metals, Grand Rapids, MI)
Wood	Incineration (Waste to energy facility, Genese, MI)
Sawdust	Landfilling (Autumn Hills RDF, Zealand, MI)
Cardboard	Recycling (Recycle America, Grand Rapids, MI)
Plastic	Recycling (Recycle America, Grand Rapids, MI)

1 sqf = square foot
2 Primary data was acquired at Steelcase Inc.; Grand Rapids, MI; August 27, 2003
3 Factory rounds; Jim Moran; Steelcase Inc.; Athens, Alabama; Aug. 2003
4 Factory rounds; Eddie Blackwell, Jim Moran; Steelcase Inc.; Athens, Alabama; Aug. 2003
5 E-mail note; Philip Hester; Steelcase Inc.; Grand Rapids, MI; June 16, 2004

and parts delivered to Steelcase. However, packaging waste accruing at Steelcase facilities from supplier deliveries was not accounted for in this study. Table 3.2.2.-5 gives an overview of manufacturing scrap/waste management strategies applied at Steelcase Grand Rapids, Michigan, facilities. Management strategies identified at Grand Rapids, Michigan, facilities were also applied for Athens, Alabama, operations with respect to this study.

Transportation

Transportation modeling regarding the Steelcase manufacturing phase considered internal forklift operation, part shipment to suppliers, and final product system delivery to customers. Transportation beyond Steelcase facilities only took into account parts and subassemblies heavier than 1 lb and/or transportation distances equal to or greater than 100 miles (see also Table 2.3.-1). According to Steelcase information, 99% of transportation outside of Steelcase operations was done by diesel trucks and -trailers.[1] Unit processes employed for trucking activities during this study were 'Truck (single) diesel FAL' and 'Trailer diesel FAL'.

Concerning forklift operation, primary data was collected at Steelcase Athens, Alabama, facilities. For feasibility purposes, use of forklifts was allocated at a fixed rate of 0.1 miles to each unit process that required internal part shipment between two different work center locations.[2] If work centers were adjacent to each other, no forklift activities were allocated. Forklifts were accounted for with respect to immediate electricity consumption, however, battery charging efficiency was considered. Average battery capacity was 53 kWh, which allowed for a travelled distance of 48 miles at an average carried load of 1200 lb.[3] At a charger efficiency of 45% this resulted in electricity demands of 4.1 kWh/tmi.[4]

3.2.3. Supplier manufacturing stage

Supplier manufacturing was tracked for externally sourced parts and components involving plastic molding-, surface coating-, steel handling-, metal casting-, and machining processes. Supplier manufacturing was accounted for with respect to major manufacturing processes taken from various data sets as shown in Table 3.1.-2 (category 'Manufacturing processes'). Related transportation activities were taken into account from supplier locations to Steelcase facilities and for parts heavier than 1 lb and/or transportation distances equal to or greater than 100 miles. Manufacturing unit processes were adapted to local conditions by replacing original energy- and transportation data with Franklin data ('Coal FAL', 'Crude oil FAL', 'Natural gas FAL', Gasoline FAL', 'Electricity avg. kWh FAL', 'Trailer diesel FAL', 'Truck FAL').

3.2.4. End of life stage

At the time this study was conducted Steelcase did not have an end-of-life product stewardship program in place (product take back, -refurbishing, -recycling, etc.). As such, the average Steelcase product system was assumed to enter the standard U.S. municipal solid waste (MSW) management system, which comprised the four main waste categories 'durable goods', nondurable goods', 'containers and packaging', and 'other wastes'.[5] For this study, Steelcase office furniture product systems were classified durable goods, whereas related packaging materials were categorized containers and packaging. Each waste category showed different rates for various materials regarding solid waste management strategies such as recycling, incinerating, and landfilling. Table 2.3.-3 (p. 19) shows recycling rates for various materials used in investigated product systems and based on the solid waste categories 'durable goods' and 'containers and packaging'. Regarding both solid waste categories, recycling rates for materials in Table 2.3.-3 were assigned based on where materials were predominantly used – furniture product systems or packaging. For plastic materials a middle ground was chosen (5.5% of materials were recycled). Waste remaining after recycling was either incinerated (14.7% of total MSW) or landfilled (56% of total MSW).[6] Recycling activities only accounted for transportation to related facilities and shredding. From a life cycle perspective, further processes were already part of the material production stage.

1 Meeting note; Steven Schneider; Steelcase Inc.; Grand Rapids, MI; July 27, 2003
2 Work center = group of machinery usually performing a set of consecutive unit processes
3 E-mail note; Darryl Long; Steelcase Inc.; Athens, Alabama; June 22, 2004
4 tmi = ton mile; 1 tmi stands for transporting 1 ton a distance of 1 mile; 1 tmi = 1.46 tkm
5 Municipal Solid Waste in the United States; U.S. Environmental Protection Agency; Washington D.C., USA; October 2001; p. 9
6 ebid; p. 14

3.3. Life cycle impact assessment (LCIA)

Based on the results of life cycle inventory analysis, life cycle impact assessment aims to quantify the importance of environmental stressors identified in an LCI and to aggregate the stressors into a small number of impact categories. It draws connections between stressors and valued areas that are potentially affected, such as human health and ecosystem functioning.[1] Current practice of LCIA addresses various impact categories, such as 'ozone depletion', 'global warming', 'eutrophication', 'ecotoxicity', 'human health criteria pollutants', 'human health cancer effects', 'human health noncancer effects', 'fossil fuel depletion/energy resource consumption', and 'land use effects'. According to De Haes, et al, life cycle impact assessment for this study was based on a bottom-up approach.[2] That is, environmental stressors identified for evaluated office furniture product systems were assigned respective impact categories, for which then midpoint indicators were calculated (see below). For example, a certain amount of sulfur dioxide (SO_2) – known for causing acid rain – was classified an acidifying emission and thus allocated the impact category 'acidification potential'. Likewise, ambient particulate matter (PM) was identified a human health hazard and thus allocated the impact category 'human health criteria pollutants'.

Not all stressors related to an impact category have the same potential regarding the impact category's environmental effect. As such, some stressors tend to be stronger while others tend to be weaker (on a per mass basis) in their contributions to the overall category impact across a product system life cycle. As a consequence, stressors are described in their relative potency to affect category impacts, that is , compared to a benchmark stressor defined for every impact category. Also, this allows for establishing final category indicators (CI), which each expresses the overall environmental relevance for an impact category as a single value. For instance, regarding the impact category 'global warming potential', the global warming potential (GWP) of carbon dioxide (CO_2) as a greenhouse gas was chosen for point of reference and set to "1". That is, 1 kg of CO_2 has a global warming potential of 1 kg CO_2 equivalent (CO_2 eqv.). As Appendix C shows, methane, in comparison, renders a GWP of 23 kg CO_2 eqv. per 1 kg of methane released into the atmosphere. In this example, the category indicator 'CO_2 eqv.' is called a midpoint indicator, which refers to the fact that it allows for evaluating stressor contributions to category impacts within the stressor–impact chain (cause–effect chain). On the contrary, endpoint indicators quantify actual damage done to specific items of interest, such as human health (immune system suppression, cataracts, cancer, etc.), ecosystems (forests, marine life, etc.), human artifacts (building stock, products, artwork, etc.), and others.[3] However, category endpoints have been highly disputed in terms of uncertainties and no best practice strategies have been identified to date.

According to the ISO 14040 standard, the process of assigning stressors to certain impact categories is called 'classification' whereas the process of defining impact potentials for stressors within an impact category is called 'characterization'.

For feasibility purposes, only four of the impact categories mentioned initially were chosen for this study, which were 'energy resource consumption', 'global warming potential', 'acidification potential', and 'human health criteria pollutants'. Additionally, those were complemented by the impact category 'solid waste'. Appendix C gives an overview of impact categories, related stressors, and their relative impact potentials as used for LCIA in this study.

As recommended in the ISO 14042 standard, LCIA

Table 3.3.-1 Cause-effect chains selected based on Ecoindicator'99- and TRACI framework

Impact category	Midpoint level selected	Level of site specificity selected	Possible endpoints
Energy resource consumption	Potential to lead to reduced availability of low cost energy supplies (fossil fuels, biomass, hydropower)	Global	Energy shortages leading to use of other energy sources, which may lead to other environmental or economic effects
Global warming potential	Potential global warming based on chemical's radiative forcing and lifetime	Global	Malaria, coastal area damage, agricultural effects, forest damage, plant and animal effects
Acidification potential	Potential to cause wet or dry acid deposition	U.S., east or west of the Mississippi River, U.S. census regions, states	Plant, animal, and ecosystem effects, damage to buildings
Human health: criteria pollutants	Exposure to elevated particulate matter less than 2.5 μm	U.S., east or west of the Mississippi River, U.S. census regions, states	Disability-adjusted life-years (DALYs), toxicological human health effects
Solid waste	Potential to cause solid waste that cannot be recycled under current technological and economic conditions	U.S., east or west of the Mississippi River, U.S. census regions, states	Shortage of landfill- and incineration capacities, toxicological effects on soil, ground-/surface water, and human health

should consider spacial dimensions of possible life cycle impacts. That is, the potential for environmental impacts of stressors should be developed based on geographic, geologic, hydrologic, and atmospheric conditions for an area stressors are likely to affect. As a consequence, the TRACI framework was selected for impact assessment purposes in this study as it was specifically designed to represent an average situation for the United States regarding stressor related environmental effects.[4] However, for the impact category 'energy resource consumption' the Ecoindicator 95 method was applied. Table 3.3.-1 shows cause-effect chains selected for the impact categories chosen.

Energy resource consumption

The impact category 'energy resource consumption' directly links environmental burdens concerning a product system to the system's overall consumption of primary energy resources. As Appendix C shows, energy resource consumption was accounted for various fossil fuels, biomass, and hydropower and was measured in lower heating values (LHV). Energy from wood and other renewables was not accounted for. An existing technique described in Ecoindicator'99 was incorporated into the TRACI framework regarding energy resource consumption, in particular for fossil fuels.[5] This technique takes into account that continued extraction and production of fossil fuels tends to consume the most economically

1 De Haes, Helias A. Udo, et al.; Life Cycle Impact Assessment, Striving Towards Best Practice; Society of Environmental Toxicology and Chemistry; Pensacola, FL, USA; 2002; p. 4
2 ebid
3 ebid; for further explanation see p. 5–6
4 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003
5 ebid; p. 68

recoverable reserves first. As a result, continued extraction becomes increasingly energy intensive in the future. This is especially true once economically recoverable reserves of conventional petroleum and natural gas are consumed, leading to the need to tap nonconventional sources, such as oil shale.

Global warming potential[1]

The impact category 'global warming potential' refers to the possible change in the earth's climate caused by the buildup of chemicals (i.e. greenhouse gases) that trap heat from the reflected sunlight that would have otherwise passed out of the earth's atmosphere. Since pre-industrial times, atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have climbed by over 30%, 145%, and 15% respectively. Although "sinks" exist for greenhouse gases – for example, oceans and land vegetation absorb CO_2 – , the rate of emissions in the industrial age has been exceeding the rate of absorption. TRACI uses global warming potentials as a midpoint metric proposed by the International Panel on Climate Change (IPCC) in order to calculate the potency of greenhouse gases relative to CO_2 (CO_2 eqv. as mentioned earlier).[2] The final sum of all stressor potentials indicates the total potential contribution to global warming regarding a product system.

Acidification potential[3]

The impact category 'acidification potential' comprises processes that increase the acidity (hydrogen ion concentration, H^+) of water and soil systems. Acid rain generally reduces the alkalinity of lakes. Changes in alkalinity of lakes are used as a diagnostic for freshwater system quality. Acid deposition also has corrosive effects on buildings, monuments, and historical artifacts. Deposition occurs through three routes: wet (rain, snow, sleet, etc.), dry (direct deposition of particles and gases onto leaves, soil, surface water, etc.), and cloud water deposition (from cloud- and fog droplets onto leaves, soil, etc.). The resulting acidification characterization factors are expressed in H^+ mole equivalent (H^+ mol eqv.) deposition per kilogram of emission. Characterization factors take into account expected differences in total deposition as a result of the pollutant release location.

Human health criteria pollutants[4]

Ambient concentrations of particulate matter (PM) are strongly associated with changes in background rates of chronic and respiratory symptoms, as well as mortality rates. Ambient particulate concentrations are elevated by emissions of primary particulates, measured as total suspended particulates, PM less than 10 µm in diameter (PM_{10}), PM less than 2.5 µm in diameter ($PM_{2.5}$), and by emissions of SO_2 and NO_x, which lead to the formation of the so-called secondary particulates sulfate and nitrate. In TRACI, human health impacts of these emissions were determined by modeling the change in exposure due to emissions, based on atmospheric reactions, emissions transport, and regional variability in population density. Second, morbidity effects and changes in mortality rates were determined based on concentration–response functions from epidemiological studies. Third, changes in morbidity- and mortality effects were aggregated into a single summary measure for disability-adjusted life-years (DALYs). The DALYs measure combines years of life lost and years lived with disability (standardized by means of severity weights).

Solid waste

The impact category 'solid waste' compiles product system related wastes, which, from an technological as well as economic perspective, are unsuitable for reuse and recycling but either are landfilled or incinerated. Solid waste comprises various residues from the raw material provision-, manufacturing-, usage-, and product retirement phases. The various types of residues subsumed under solid waste in this study can be viewed in Appendix C. Solid waste is reported in kilograms of material.

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003; p. 56

2 IPCC; Houghton, J. T., et al.; Climate change 1995: The science of climate change; Cambridge University; Cambridge, UK; 1996

3 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003; p. 56–57

4 ebid; p. 62–63

4. Results and discussion

In this section the methodology described in Chapter [3.] is used to evaluate environmental burdens for the lateral file product system, the panel product system and the worksurface product system. The results are reported per product in Section [4.1.] and per kg of product in Section [4.2.].

The environmental burdens evaluated are energy resource consumption, global warming potential, acidification potential, criteria pollutants, and solid waste (excluding recyclables). The impact categories are described in greater detail in Section [3.3.].

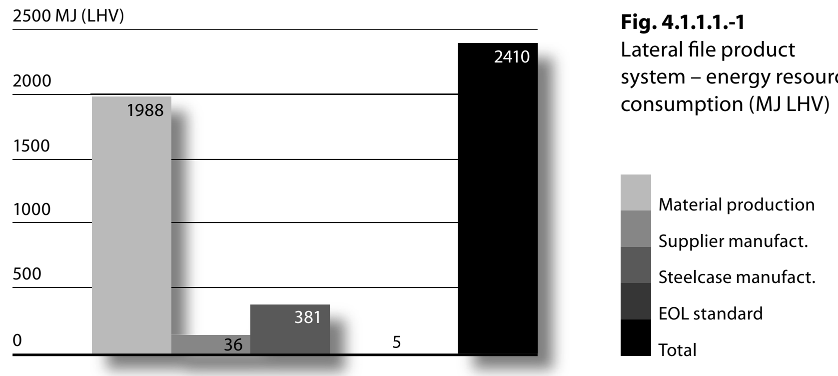


Fig. 4.1.1.1.-1
Lateral file product system – energy resource consumption (MJ LHV)

4.1. Product specific results and discussion

4.1.1. Lateral file product system

4.1.1.1. Lateral file product system results

Energy resource consumption

The impact category energy resource consumption is derived from the Ecoindicator'99 method.[1] It directly correlates environmental burdens related to a product system to the system's overall consumption of primary energy resources. In this study, fossil fuels, biomass, and hydropower are accounted for.

Fig. 4.1.1.1.-1 shows the life cycle energy use for the lateral file product system, which totals 2410 MJ of lower heating value. It can be seen that across all life cycle stages the material production stage is by far the most energy intensive stage (1988 MJ, 82%), followed by the Steelcase stage (381 MJ, 16%), the supplier stage (36 MJ, 1.5%), and the end-of-life (EOL) stage (5 MJ, 0.3%).[2]

As depicted in Fig. 4.1.1.1.-2, the major energy consumers in the material production stage are cold-rolled steel with 1540 MJ and hot-rolled steel with 128 MJ (combined, both represent 84% of stage total and 69% of system total). This is due to the fact that steel manufacturing requires about one kg of coal for every kilogram of steel produced. Also, steel accounts for 98% of the total lateral file product system weight. As such, energy resource consumption, with respect to steel production, makes up for a similarly high fraction of the product system's overall life cycle energy demand.

The supplier stage accounts for 36 MJ of energy consumption for part fabrication processes not done at Steelcase facilities and not already embedded in the material production stage. In other words, the supplier stage comprises the manufacturing of parts and subassemblies, which can be readily applied in the final lateral file product system (screws, small plastic parts, glides, etc.), as well as special treatments for parts originally manufactured at Steelcase and sent back to Steelcase after the treatment (surface coating processes, etc.). For the lateral file product system, those supplier processes are cold transforming steel like blanking and stamping (28 MJ, 79% of stage total), non-ferro cast work (3.5 MJ, 10% of stage total), zinc coating (3.2 MJ, 9% of stage total), PE extrusion (0.6 MJ, 1.6% of stage total), electroplating nickel, electroplating chrome, and machining aluminium.

Regarding the Steelcase stage, almost 99% of the energy resource demand per lateral file is related to electricity consumption (Electricity_ConsumersEnergy) for powder coating (192 MJ, 52% of stage total), welding

(68 MJ, 18% of stage total), compressed air (43 MJ, 11% of stage total), machinery (42 MJ, 11% of stage total), cooling water (16 MJ, 4% of stage total), and overhead related activities (5.26 MJ, 1.5% of stage total). As such, powder coating processes, welding processes, and the provision of compressed air account for 85% of total energy resources consumed at Steelcase facilities during the manufacturing of a single lateral file product system. Forming involved in producing the lateral file product system is mainly done on large and medium sized hydraulic- and mechanical presses, which are responsible for most of the remainder in electricity consumption. More detailed information on Steelcase manufacturing equipment can be found in Section [3.2.2.].

Compared to the other three life cycle stages, the EOL stage can be considered negligible in terms of energy resource consumption. Plastic incineration during this life cycle stage accounts for -5 MJ in energy recovered, which reduces this stage's overall energy resource consumption from 10 MJ to 5 MJ (below threshold and not shown in Fig. 4.1.1.1.-2).[3]

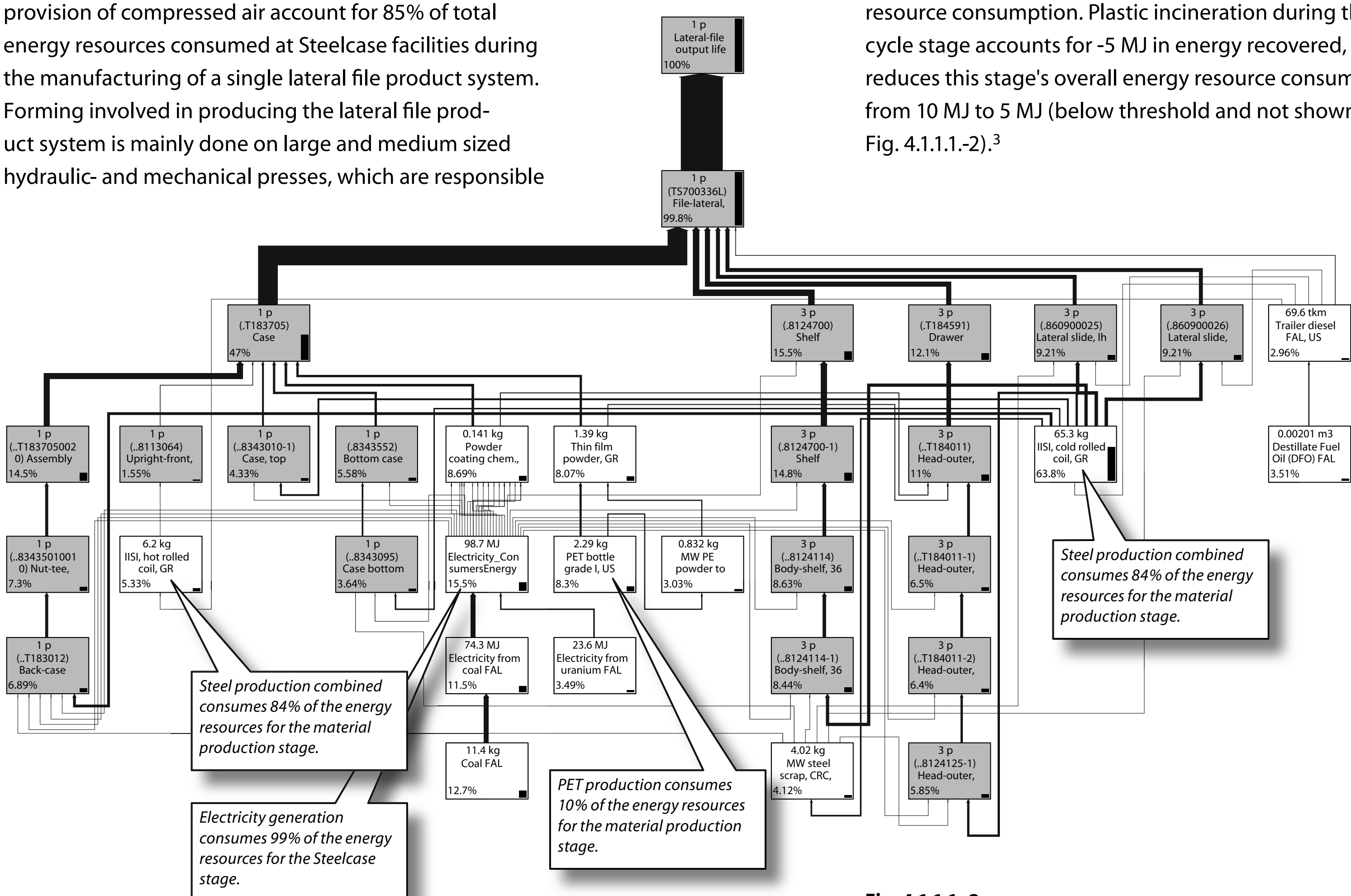


Fig. 4.1.1.1.-2
Flow diagram of lateral file energy resource consumption in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Goedkoop, M.; "The Ecoindicator'99", Final Report; NOH Report 9523; Pré consultants; Amersfoort, The Netherlands, 1999
2 Energy is reported in Lower Heating Values (LHV)
3 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Global warming potential

The impact category 'global warming potential' evaluates the environmental impacts in terms of global climate change due to the build-up of chemicals (greenhouse gases) that trap heat from the reflected sunlight, which would have otherwise passed out of the earth's atmosphere. The potency of various greenhouse gases concerning their global warming potential is expressed relative to that of carbon dioxide (CO_2 eqv.).[1] The most powerful greenhouse gases evaluated in this impact category are N_2O (296 kg CO_2 eqv.), methane (23 kg CO_2 eqv.), and CO_2 (1 kg CO_2 eqv.).

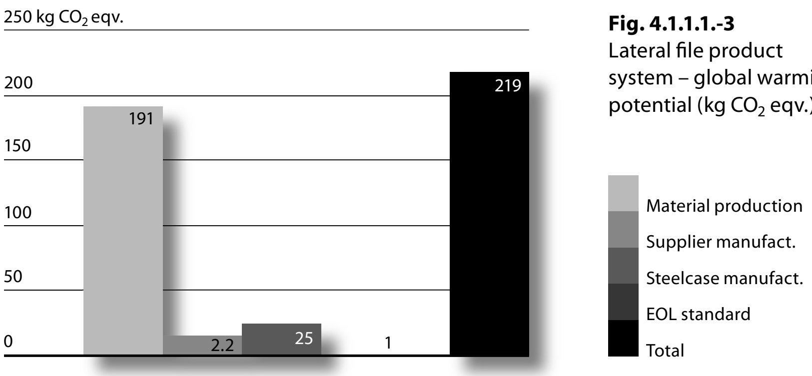


Fig. 4.1.1.1.-3
Lateral file product system – global warming potential (kg CO_2 eqv.)

The global warming potential for the lateral file product system adds up to 219 kg CO_2 eqv. and corresponds closely with the distribution of energy resource consumption across the four life cycle stages (Fig. 4.1.1.1.-3). The material production stage accounts for 191 kg (87%), the Steelcase stage for 25 kg (11%), the supplier stage for 2.2 kg (1%), and the EOL stage for 1 kg (0.5%) in CO_2 equivalents (CO_2 eqv.).

According to Fig. 4.1.1.1.-4, steel manufacturing accounts for the largest fraction of global warming potential for the material production stage (178 kg, 93% of stage total; 81% of system total). The remainder is associated with thin-film powder production (5.33 kg, 3% of stage total), electricity generation (3.2 kg, 2% of stage total), and others, such as manufacturing waste handling and the provision of chemicals used in powder coating processes (below threshold of 3% and not shown in Fig. 4.1.1.1.-4).

The supplier stage contributes 2.2 kg in CO_2 eqv. to the overall global warming potential of the lateral file product system. Within this stage, cold transforming steel, zinc coating, and non-ferro cast work are the most influential processes, adding 1.7 kg (77% of stage total), 0.23 kg (10.5% of stage total), and 0.22 kg (10% of stage total) in CO_2 eqv. to the supplier stage respectively.

For the Steelcase stage almost 99% of global warming potential per lateral file can be assigned to the provision of electricity (Electricity_ConsumersEnergy) used in powder coating (12.7 kg CO_2 eqv., 52% of stage total), welding (4.5 kg CO_2 eqv., 18% of stage total), compressed air (2.9 kg CO_2 eqv., 12% of stage total), machinery (2.8 kg CO_2 eqv., 11% of stage total), cooling water (1 kg CO_2 eqv., 4% of stage total), and overhead related activities (0.5 kg CO_2 eqv., 2% of stage total).

As with the impact indicator 'energy resource consumption', the global warming effects caused by the EOL stage can be considered minor compared to the three preceding stages. By releasing 1 kg CO_2 eqv. of greenhouse gases, the EOL stage contributes less than 0.5% to the lateral file product system's total global warming potential.[2]

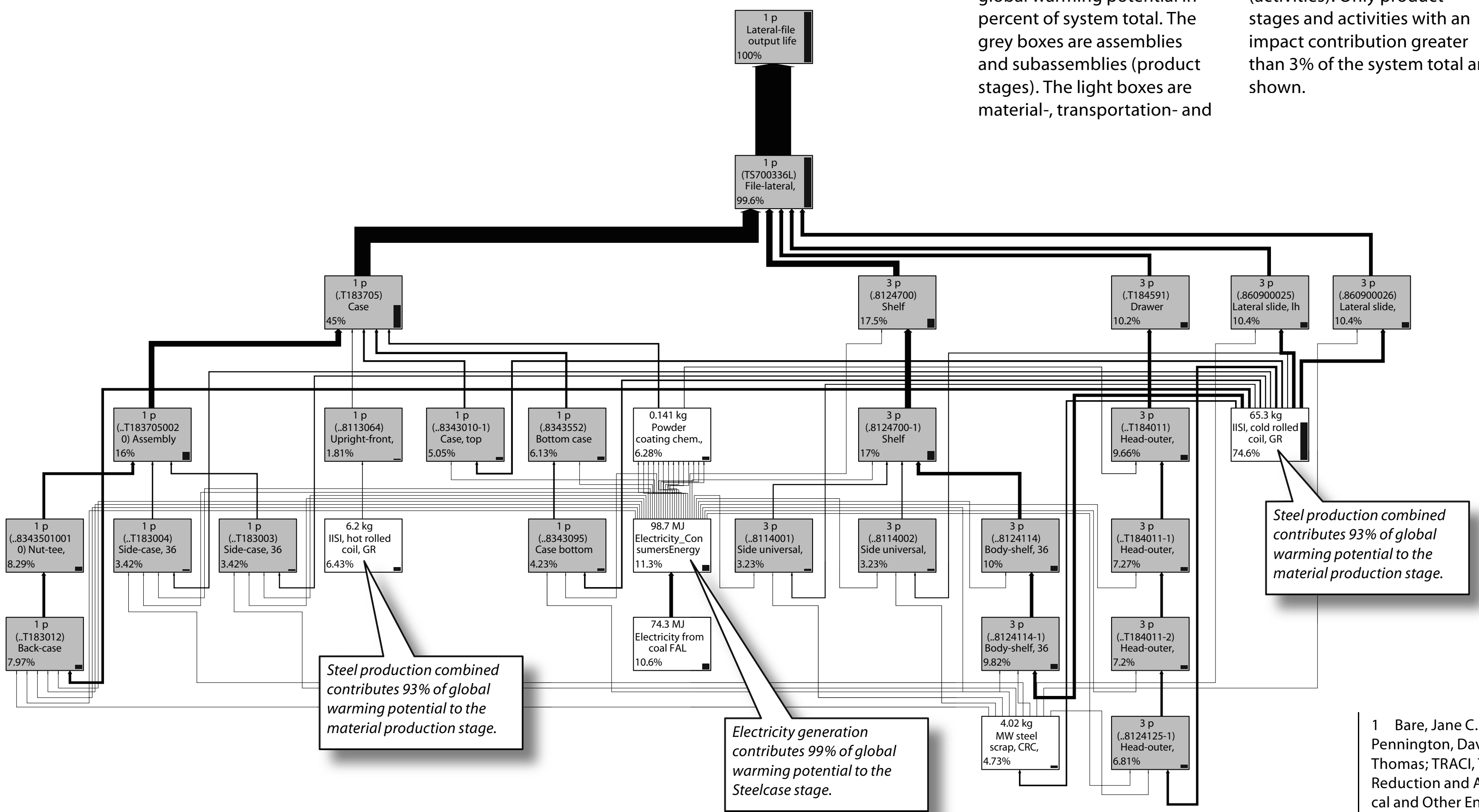


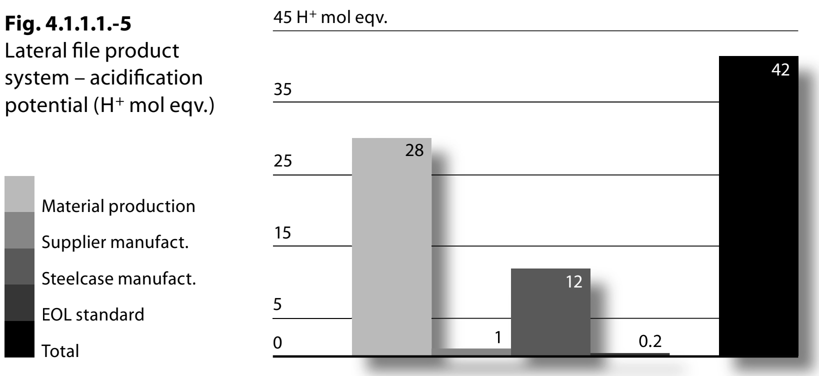
Fig. 4.1.1.1.-4:
Flow diagram of lateral file global warming potential in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003
2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Acidification potential

The impact category 'acidification potential' refers to the deposition of negatively charged ions into the environment, which leaves excess hydrogen ion concentrations (H^+) in the system. Acidification characterization factors are expressed in H^+ mole equivalent depositions per kg of emission from a product system.[1] The most potent substances in terms of acidification potential considered in this impact category are ammonia (95.5 H^+ mol eqv./kg), hydrofluoric acid (HF; 81 H^+ mol eqv./kg), nitric acid (NO; 61 H^+ mol eqv./kg), and sulfur dioxide (SO_2; 50.1 H^+ mol eqv./kg).

Fig. 4.1.1.1.-5
Lateral file product system – acidification potential (H^+ mol eqv.)



The lateral file product system's total acidification potential is 42 H^+ mol eqv. Accordingly, the individual contributions to the four different life cycle stages are 28 H^+ mol eqv. (67%) for the material production stage, 12 H^+ mol eqv. (29%) for the Steelcase stage, 1 H^+ mol eqv. (2.5%) for the supplier stage, and 0.2 H^+ mol eqv. (0.5%) for the EOL stage.

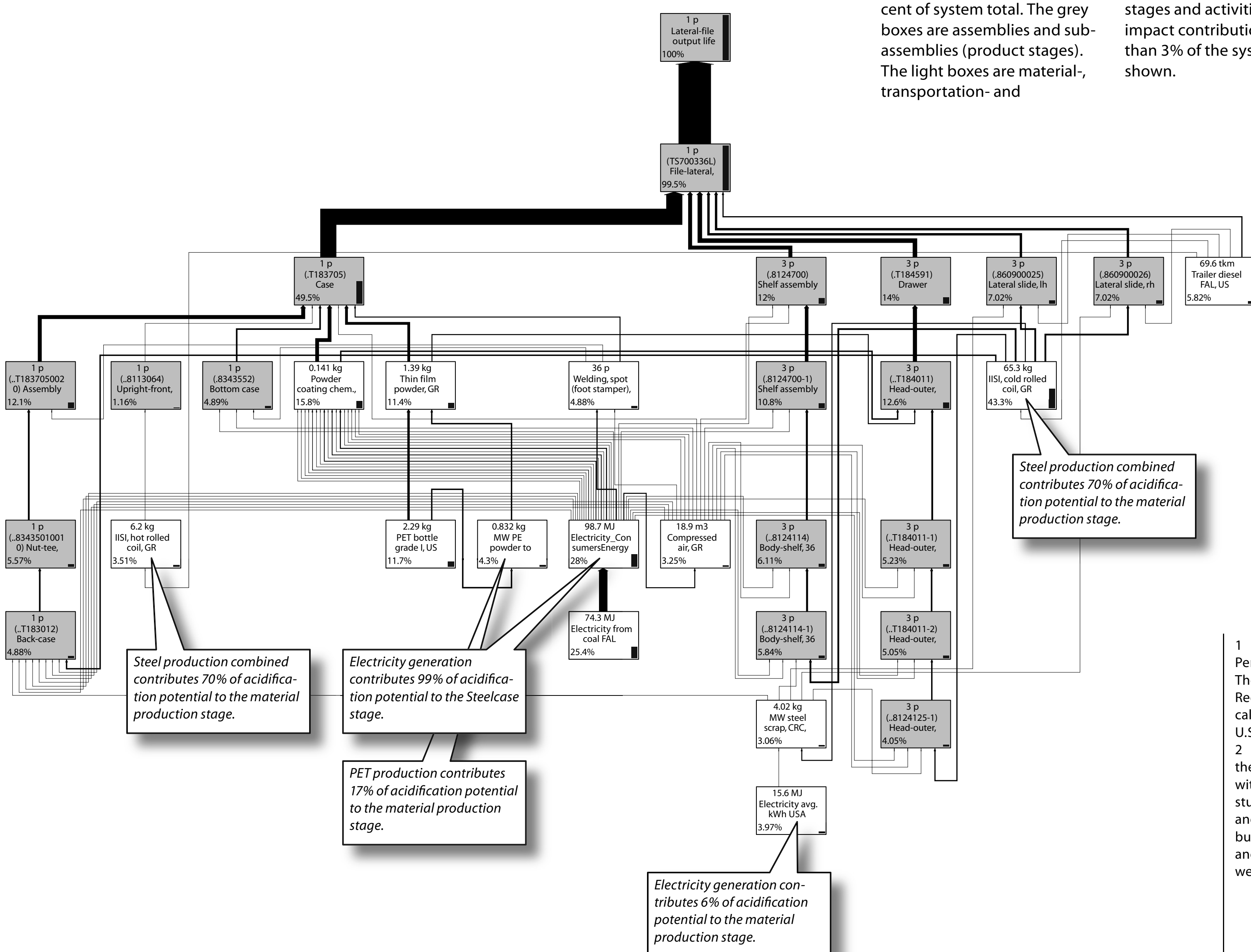
The material production stage is again the most dominant stage with respect to the product system's total acidification potential. According to Fig. 4.1.1.1.-6, the major contributors to this stage are steel manufacturing (19.5 H^+ mol eqv., 69.5% of stage total; 46% of system total), PET production related to thin-film powder fabrication (4.9 H^+ mol eqv., 17% of stage total), and electricity generation (1.7 H^+ mol eqv., 6% of stage total). Minor contributors are aluminum- (0.31 H^+ mol eqv., 1% of stage total), copper- (0.2 H^+ mol eqv., 0.7% of stage total), zinc- (0.1 H^+ mol eqv., 0.4% of stage total), and plastics production (0.1 H^+ mol eqv., 0.4% of stage total), as well as the provision of process heat (0.2 H^+ mol eqv., 0.6% of stage total).

The supplier stage accounts for 1 H^+ mol eqv. in acidification potential. The majority is caused by cold transforming steel (0.87 H^+ mol eqv., 77% of stage total), zinc coating (0.23 H^+ mol eqv., 11% of stage total), and non-ferro cast work (0.22 H^+ mol eqv., 10% of stage total).

For the Steelcase stage, almost all contributions to acidification potential stem from the use of electricity (Electricity_ConsumersEnergy) for powder coating (6 H^+ mol eqv., 52% of stage total; 14% of system total), welding (2 H^+ mol eqv., 18% of stage total), compressed air (1.35 H^+ mol eqv., 12% of stage total), and machinery (1.3 H^+ mol eqv., 11% of stage total). Together, these activities account for 93% of the Steelcase stage's total acidification potential. Less influential contributors are the handling of cooling water (pumping, etc.), the operation of individual (workplace) fans, and general overhead with 0.5 H^+ mol eqv. (4% of stage total), 0.18 H^+ mol eqv. (1.5% of stage total), and 0.16 H^+ mol eqv. (1.4% of stage total) respectively. Compared to energy resource consumption, the Steelcase stage shows a disproportionately high acidification potential. This can be attributed to both the high fraction of electricity generated from coal within the Consumers Energy Co. utility system (see also Section [3.2.2.]) and the use of lower sulfur fuels in other product system stages.

Similar to the impact categories already addressed, the EOL stage contributes insignificantly to the lateral file product system's overall acidification potential. With releases of 0.2 H^+ mol eqv. it accounts for 0.5% of the product system's total impact on acidification.[2]

Fig. 4.1.1.1.-6
Flow diagram of lateral file acidification potential in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.



1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Criteria pollutants

The impact category 'criteria pollutants' addresses ambient particulate matter, which is strongly associated with changes in background rates of chronic and acute respiratory symptoms, as well as mortality rates. The human health effects are reported in DALYs (disability-adjusted life-years), which is a combined measure for the years of life lost and years lived with disabilities due to the exposure to criteria pollutants.[1] The most severe criteria pollutants addressed in this impact category are particulates ($PM_{2.5}$, PM_{10}; 0.139 DALYs/kg, 0.08345 DALYs/kg), and sulfur dioxide (SO_2; 0.0139 DALYs/kg).

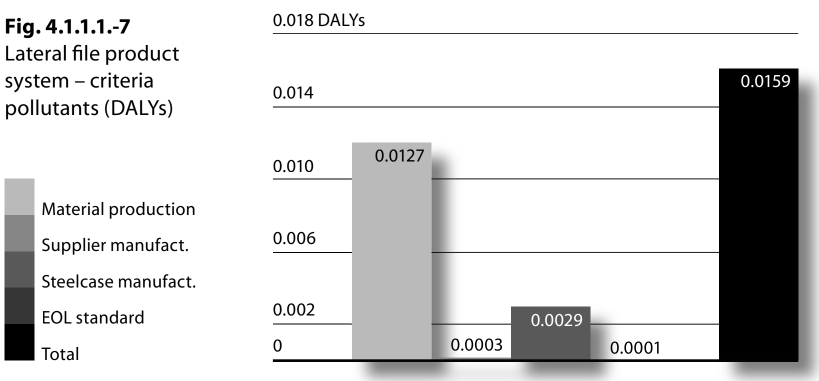


Fig. 4.1.1.1.-7
Lateral file product system – criteria pollutants (DALYs)

As depicted in Fig. 4.1.1.1.-7, criteria pollutants for the lateral file product system total in 0.016 DALYs and follow a similar pattern as seen with the environmental impact categories before. That is, the material production stage has the highest emissions, amounting to 0.0127 DALYs (79%), followed by the Steelcase stage (0.0029 DALYs, 18%), the supplier stage (0.0003 DALYs, 2%), and the EOL stage (0.0001 DALYs, 0.6%).

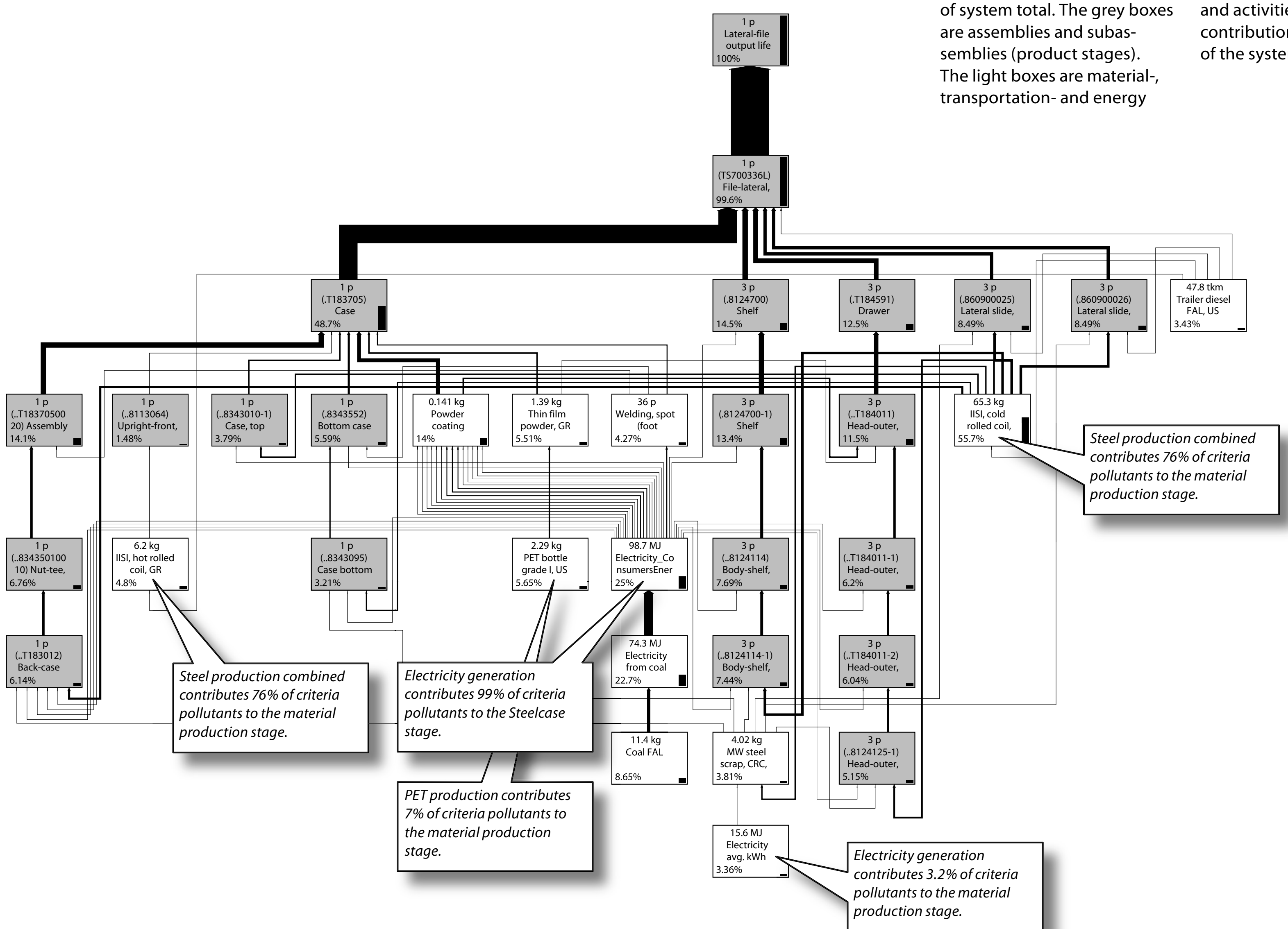
The material production stage in terms of criteria pollutants mainly comprises steel manufacturing (0.0096 DALYs, 76% of stage total; 61% of system total), PET production related to thin-film powder fabrication (0.0009 DALYs, 7% of stage total), and electricity generation (0.0004 DALYs, 3.2% of stage total), (Fig. 4.1.1.1.-8). Less influential flows are aluminum- (0.0001 DALYs, 0.6% of stage total) and copper fabrication (0.0001 DALYs, 0.4% of stage total), as well as the provision of process heat (0.0001 DALYs, 0.4% of stage total).

For the supplier stage the major contributors are cold transforming steel (0.0002 DALYs, 77% of stage total), non-ferro cast work (0.00003 DALYs, 12% of stage total), and zinc coating (0.00001 DALYs, 6% of stage total).

Regarding the Steelcase stage, the greatest amount of criteria pollutants is released due to electricity use/generation (Electricity_ConsumersEnergy, 99% of stage total). The main contributors to this stage are powder coating (0.0015 DALYs, 51% of stage total), welding (0.0005 DALYs, 18% of stage total), machinery (0.0003 DALYs, 12% of stage total), and compressed air (0.0003 DALYs, 11% of stage total). Minor contributions are related to cooling water (1.2E-4 DALYs, 4% of stage total), individual fan operation (4.2E-5 DALYs, 1.5% of stage total), and general overhead (3.9E-5 DALYs, 1.4% of stage total).

Once more, the EOL stage appears to be negligible with respect to the lateral file product system's overall generation of criteria pollutants (0.0001 DALYs, 1% of system total).[2]

Fig. 4.1.1.1.-8
Flow diagram of lateral file criteria pollutants in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.



1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Solid waste (excluding recyclables)

The impact category 'solid waste' indicates environmental burdens with respect to the usage of landfill volume, the generation of non-recovered materials, and the overall material efficiency of a product system. The measure is kilograms of solid waste produced throughout the life cycle of a product system.

As shown in Fig. 4.1.1.1.-9, generation of solid waste across the lateral file product system life cycle deviates from previous impact categories. Here, main contributions occur during the EOL stage (49 kg, 71%), followed by the material production stage (13.8 kg, 20%), the Steelcase stage (5.4 kg, 7.8%), and the supplier stage (0.4 kg, 0.5%). With respect to the Steelcase stage, it has to be mentioned that manufacturing scrap/waste is not included as it is subsequently recycled (i.e. steel scrap). As such, solid waste for the Steelcase stage only comprises waste associated with off-site electricity generation, as well as other energy provision activities and waste related to treatment processes besides recycling.

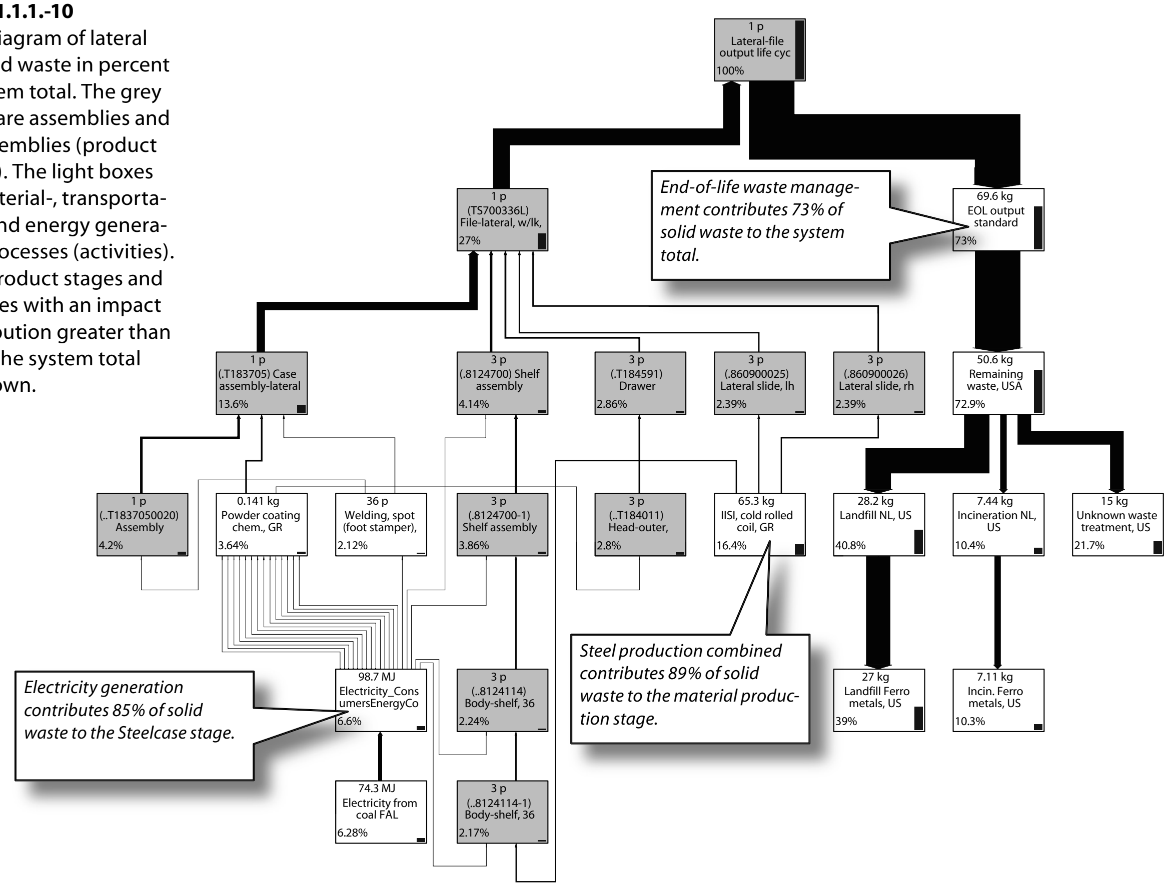
The solid waste total for the lateral file product system is 69 kg (Fig. 4.1.1.1.-10). The major contributors regarding the material production stage are steel manufacturing (12.3 kg, 89% of stage total; 18% of system total), copper production (0.75 kg, 5.4% of stage total), electricity generation (0.5 kg, 3.5% of stage total), and aluminum fabrication (0.4 kg, 3% of stage total). Minor contributions to the material production stage regarding solid waste come from PET- (0.1 kg), zinc- (0.01 kg) and plastics manufacturing (0.01 kg).

Concerning the supplier stage, most of the solid waste is generated during cold transforming steel (0.28 kg, 91% of stage total), followed by non-ferro cast work (0.02 kg, 7% of stage total), and electroplating nickel (0.002 kg, 0.8% of stage total).

Eighty-five percent of the Steelcase stage solid waste is related to electricity consumption (Electricity_ConsumersEnergy). Activities, which contribute the most to electricity consumption are powder coating (2.4 kg, 44% of stage total), welding (0.8 kg, 15% of stage total), machinery (0.6 kg, 11% of stage total), and compressed air (0.5 kg, 9% of stage total). Powder coating overspray results in 0.3 kg (12% of stage total) in solid waste that is ultimately landfilled.[1]

The EOL stage accounts for 49 kg in solid waste and is by far the biggest contributor in terms of solid waste generation throughout the lateral file product system life cycle.[2] This is due in particular to the retirement of the whole lateral file product system itself

Fig. 4.1.1.1.-10
Flow diagram of lateral file solid waste in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.



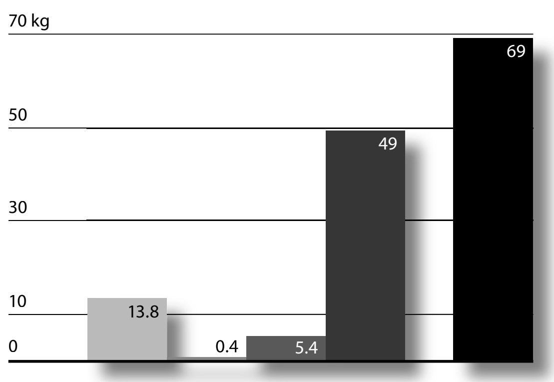


Fig. 4.1.1.1.-9
Lateral file product system – solid waste (kg)

and the processing of durable goods within the U.S. municipal waste management system.[3]

Manufacturing material Utilization

As shown in Table 4.1.1.1.-1, five kg of manufacturing scrap/waste is generated at Steelcase facilities (Steelcase stage), which represents 6.9% of total materials used (product weight + manufacturing scrap/waste). Since there is little or no specific information available from suppliers on how much waste was caused by manufacturing parts at their locations, default values for manufacturing scrap/waste are used from related data sources (listed under 'manufacturing processes' in Table 3.1.-2) in this study.[4] Regarding the Steelcase stage, manufacturing scrap/waste is particularly generated during steel-handling processes (4.2 kg, 5.9% of steel total) – mainly stamping, blanking, and laser-cutting – as well as powder coating (0.83 kg, 36% of plastics total). For the latter, waste generation is due to the low material utilization rate of 60% (ratio of thin-film powder staying attached to the part and total powder used). As such, and as mentioned in Section [3.2.2.], the remaining 40% of the total amount of thin-film powder turns into waste and cannot be recycled at this point due to the mixing of different colors but has to be landfilled.[5]

Manufacturing scrap during steel stamping, -blanking, and -cutting operations mainly comes from curved, undulated, or voided part outlines and/or numerous orifices across part surfaces. In many cases manufacturing scrap/waste is also related to the overall amount of material(s) going into a product system. Steel manufacturing scrap generated at Steelcase facilities is fully recycled.[6] Fig. 4.1.1.1.-11 shows a graphical depiction of the two major manufacturing scrap/waste streams for the lateral file product system.

Table 4.1.1.1.-1 Materials and manufacturing scrap/waste associated with lateral file product system

Materials	Materials used in product	Man. scrap/ waste at SC[7]		% of materials lost	
Steel					
IISI, cold rolled coil	61.200	4.020	kg(r)		
IISI, hot rolled coil	6.000	0.192	kg(r)		
Steel total	*67.200*	*4.212*	*kg*	*5.9*	*%*
Aluminum					
AlCuMgPb (2011) I, US	0.051	N/A[4]	kg		
Aluminum total	*0.051*	*-*	*kg*	-	
Non-ferro					
Zinc	0.033	N/A	kg		
Non-ferro total	*0.033*	*-*	*kg*	-	
Plastics					
LLDPE film FAL	0.001	negligible	kg		
LDPE film FAL	0.002	negligible	kg		
PA 6 I, US	0.009	N/A	kg		
PA 6.6 A, US	0.020	N/A	kg		
PE granulate average B250, US	0.002	N/A	kg		
PET bottle grade I, US	1.390	0.831	kg(l)		
PVC FAL	0.005	N/A	kg		
SAN A, US	0.086	N/A	kg		
Plastics total	*1.513*	*0.831*	*kg*	*36*	*%*
Product system total	***68.800***	***5.043***	***kg***	***6.9***	***%***

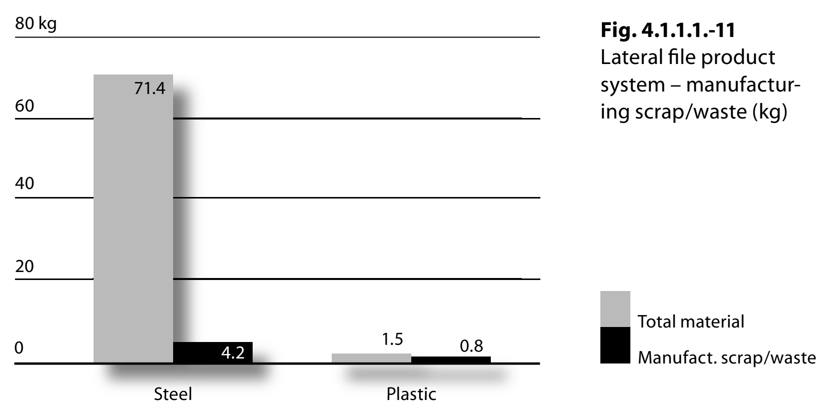


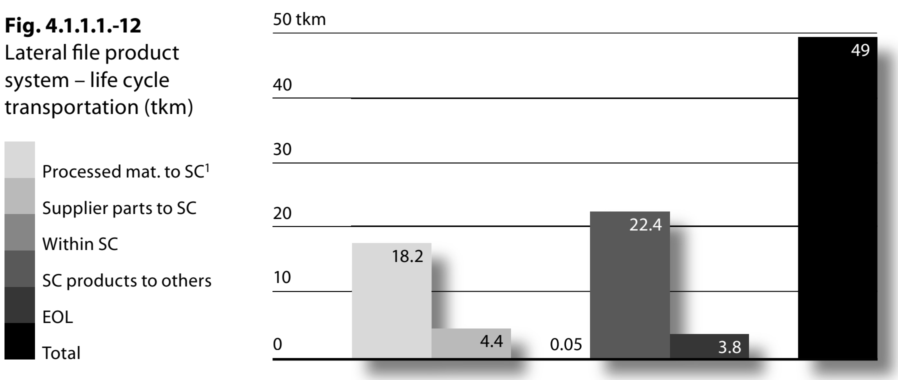
Fig. 4.1.1.1.-11 Lateral file product system – manufacturing scrap/waste (kg)

1 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; June 18, 2004
2 As mentioned in Section [], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for
3 A detailed description of the EOL waste management scenario applied in this study can be found in Section [2.3.]
4 N/A = no information available
5 Meeting note; Steelcase Inc.; Grand Rapids, MI; August 27, 2003
6 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; June 18, 2004
7 SC = Steelcase; (r) = recycled; (l) = landfilled

Transportation

As part of this study, transportation activities were recorded for processed materials, parts shipped from suppliers to Steelcase, parts and assemblies transported within and between Steelcase facilities, and final products delivered from Steelcase to customers. For feasibility purposes, transportation activities with respect to raw material acquisition are not reported separately, since related data is fully embedded in the material production processes. A list of all material production processes applied in this study can be found in Table 3.1.-2. Means of transportation investigated are single-unit trucks (diesel), tractor trailers (diesel), forklift operation (electric), rail transport (diesel), and waterborne vessels (fuel oil). Transportation needs are expressed in tkm (tonkilometers), that is, one tkm represents the movement of one metric ton (1 t = 1000 kg) over a distance of 1 kilometer (1 km = 1000 m) – or the transport of 0.5 metric ton over 2 km, etc. Underlying data and assumptions for transportation activities are stated in Sections [2.3.] and [3.2.2.].

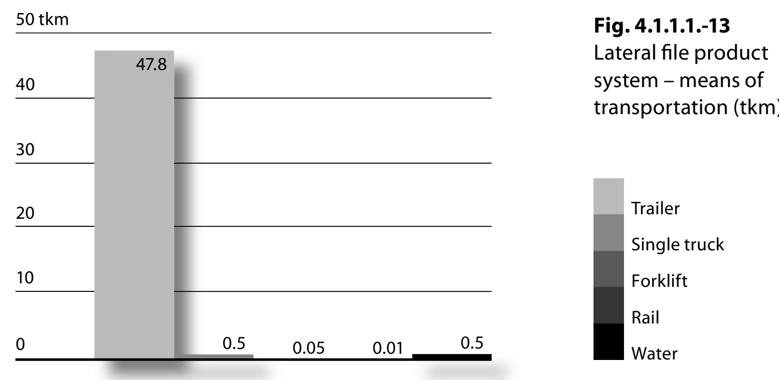
Fig. 4.1.1.1.-12
Lateral file product system – life cycle transportation (tkm)



The majority of transportation activities are related to shipping products and materials from Steelcase to other destinations (22.4 tkm, 46% of system total)(Fig. 4.1.1.1.-12), as either final goods to end customers (21.9 tkm, 44.7% of system total) or production related materials, like manufacturing scrap/waste, to subsequent uses or treatment stages (0.5 tkm, 1.3% of system total). Delivering processed materials (steel, fabrics, wood, chemicals, etc.) to Steelcase- as well as supplier facilities (18.2 tkm, 37% of system total) is the second most intense transportation activity. Third is shipping parts and subassemblies from supplier- to Steelcase sites (4.4 tkm, 9% of system total), followed by transporting materials related to the product's end-of-life (EOL) to various waste management facilities (3.8 tkm, 7.8% of system total), and hauling parts and assemblies within Steelcase operations predominantly by electric forklifts (0.05 tkm, 0.1% of system total). In total, transportation activities related to one lateral file product system equals 49 tkm. Expressed in terms of the product system's own weight of 68.8 kg, this is equal to moving a lateral file product system over a total distance of 712 kilometers (450 miles).

As depicted in Fig. 4.1.1.1.-13, the most dominant means of transportation is diesel trailers, which account for 47.8 tkm (98% of system total) in materials and goods shipped. As such, diesel trailers are responsible for most of the 50 MJ (LHV) in total transportation energy associated with a single lateral file product system. On the other end, forklift operation results in 0.05 tkm of transportation within Steelcase facilities, which equals moving a single lateral file product system 0.73 kilometers (0.5 miles).

Fig. 4.1.1.1.-13
Lateral file product system – means of transportation (tkm)



Specific flows

In Table 4.1.1.1.-2, various material- and energy flows are viewed more specifically in order to make them more readily understandable from an operations point of view. Environmental impacts for the grayed items were already accounted for previously as part of the five general life cycle impact categories ‘energy resource consumption’, ‘global warming potential’, ‘acidification potential’, ‘criteria pollutants’, and ‘solid waste’. Besides these, however, Table 4.1.1.1.-2 introduces water consumption and overhead intensity as additional environmentally relevant measures.

As depicted in Table 4.1.1.1.-2, the manufacturing of the lateral file product system consumes a substantial amount of fresh water (1570 kg, equal to 415 gallons), of which 30 kg are used at Steelcase facilities for overhead and cooling water purposes. 1444 kg of the remaining water is used in steel production. Overhead intensity is derived from individual floor space covered by manufacturing equipment and part throughput of that very equipment per hour. Overhead intensity, is thus an indicator for space- and manufacturing efficiency. Oils and lubricants are an indicator of potentially hazardous wastes eventually being landfilled.[2]

By looking at the electricity consumed for the manufacturing of a lateral file product system, it becomes apparent that 85% of the total amount of 31.4 kWh is used at Steelcase locations. Despite that most of the natural gas (82% of system total) related to the production of a lateral file product system is used outside of Steelcase facilities, 75% of the system total ultimately is used for electricity generation.

Table 4.1.1.1.-2 Specific material- and energy flows associated with lateral file product system

Flow	Amount	
Materials in product, total	68.80	kg
Manufacturing waste @ Steelcase	5.04	kg
Water, total	1570.00	kg
Water @ Steelcase	29.9	kg
Overhead intensity @ Steelcase	22.40	m^2
Workspace lighting @ Steelcase	0.78	kWh
Individual fan operation @ Steelcase	0.41	kWh
Electricity, total	31.40	kWh
Electricity @ Steelcase	26.70	kWh
Natural gas, total	4.80	kg
Natural gas @ Steelcase	0.10	kg
Oils & lubricants @ Steelcase	0.01	kg

1 SC = Steelcase; in this case also includes supplier facilities

2 Meeting note; Angeline Forton; Steelcase Inc.; Grand Rapids, MI; July 25, 2003

4.1.1.2. Lateral file product system discussion

This section looks at the environmental burdens related to the manufacturing of a lateral file product system from a systems perspective. Table 4.1.1.2.-1 gives an overview of the LCA's main results reported in Section [4.1.1.1.].

Material production stage

As can be seen from the pie charts in Table 4.1.1.2.-1 (% of system total), the material production stage is the most dominant stage, both across all life cycle stages and with respect to the entirety of impact categories except for 'solid waste' and 'transportation'.[1] For the latter, it has to be mentioned that this study does not explicitly report transportation activities during raw material acquisition since those are already embedded in the material production processes and cannot be easily discerned (see also Section [4.1.1.1.]). Within the material production stage, steel fabrication is the single most important contributor to environmental burdens across all impact categories. This is mainly due to the lateral file product system's high usage of cold- and hot rolled steel as main construction materials and to the manufacturing processes associated with these types of steel. In general, virgin steel production shows an energy intensity between 21-40 MJ/kg, while recycled steel is as low as 10 MJ/kg.[2] For comparison purposes, Table 4.1.1.2.-2 shows energy intensities for various common manufacturing materials.

Other considerable environmental impacts throughout the material production stage are caused by plastic manufacturing, in particular PET, as well as the provision of non-ferro metals such as aluminum and copper. While aluminum and copper mainly contribute to the generation of solid waste (mining tailings etc.), the production of PET has a substantial effect on the product system's overall acidification potential. The consequences of the usage of PET, and to a much higher degree of aluminum and copper, are especially noteworthy as these materials represent only a small percentage of the lateral file total product weight, which is 3%, 0.1%, and 0.01% respectively. 69% of the copper used (0.008 kg) does not become part of the final product but is used in welding tips, which last for about 3000 welding spots.[3]

Table 4.1.1.2.-2 Material comparisons based on energy resource consumption for production

Material	Energy res. cons.	
Steel, cold rolled coil (IISI)	24	MJ/kg
Steel, hot rolled coil (IISI)	21	MJ/kg
Steel, section, EAF route, 100% rec. (IISI)	10	MJ/kg
Copper (Idemat)	92	MJ/kg
Aluminum, primary (Idemat)	192	MJ/kg
Aluminum, 80% rec. (Idemat)	19	MJ/kg
PA 6.6 (Nylon, APME)	142	MJ/kg
PET bottle grade (APME)	79	MJ/kg
PVC (APME)	57	MJ/kg
Kraft paper (Franklin)	35	MJ/kg
Kraft unbleached, 100% rec. (Franklin)	17	MJ/kg
Particleboard (BEES)	12	MJ/kg
Wood, oak (Idemat)	10	MJ/kg
Wood, silver fir (Idemat)	2	MJ/kg

Supplier manufacturing stage

The supplier stage is the least influential of all life cycle stages for the lateral file product system (Table 4.1.1.2.-1). This is mainly due to the low volume of materials handled through energy intensive processes and/or processes, which comprise hazardous substances such as aluminum casting (0.08 kg) and zinc coating (0.033 m^2).[4] Conversely, a higher volume of materials is handled through less energy intensive processes like transforming steel (17 kg). As materials and parts are shipped between Steelcase- and supplier locations, this stage shows the third highest transportation activities (4.4 tkm).

Steelcase manufacturing stage

The Steelcase stage causes the second largest impact on the environment across all life cycle stages, primarily by requiring 27.5 kWh of electricity (Electricity_ConsumersEnergy) for every lateral file product system manufactured. As shown in Table 4.1.1.2.-1, most electricity for the Steelcase stage is consumed by powder coating, welding, compressed air, and machinery, which accounts for 94% of stage total environmental burdens across all impact categories except for 'transportation'. Powder coating alone represents 56% of electricity usage particularly due to various electrically operated heating ovens.[5]

Transportation activities add up to 2% of the lateral file product system's total energy resource consumption, of which 47% is associated with diesel trailers for shipping the final product system to customers.

End-of-life stage

As depicted in Table 4.1.1.2.-1, the end-of-life stage is almost negligible in terms of most of the environmental impact categories except for 'solid waste'.[1] Solid waste accrued during this stage, however, accounts for 73% of total solid waste generated throughout the entire lateral file product system life cycle. This is due in particular to the retirement of the lateral file product system itself. As described in Section [2.3] U.S. EPA data on waste management for durable goods (which comprises furniture products) as well as for packaging materials report recycling rates of 28% for steel, 0% for aluminum, 60% for other non-ferro metals, and 5.5% for plastics.[6] Since, as of yet, Steelcase does not have a deliberate end-of-life

Table 4.1.1.2.-1 LCA results for manufacturing a lateral file product system reported for various impact categories and along all life cycle stages

Impact category		**Product life cycle stage** Material production	Supplier manufacturing	Steelcase manufacturing	End-of-life
Energy resource consumption (2410 MJ LHV)	% of system total	82%	1.5%	16%	0.3%
	% of stage total	- 84% steel production	- 79% transforming steel - 10% non-ferro cast work - 9% zinc coating	- 56% powder coating - 18% welding - 11% compressed air - 9% machinery	
Global warming potential (219 kg CO_2 eqv.)	% of system total	87%	1%	11%	0.5%
	% of stage total	- 93% steel production - 3% PET production	- 77% transforming steel - 11% non-ferro cast work - 10% zinc coating	- 53% powder coating - 18% welding - 12% compressed air - 10% machinery	
Acidification potential (42 H^+ mol eqv.)	% of system total	67%	2.5%	29%	0.5%
	% of stage total	- 70% steel production - 17% PET production	- 77% transforming steel - 11% non-ferro cast work - 10% zinc coating	- 53% powder coating - 18% welding - 12% compressed air - 10% machinery	
Criteria pollutants (0.0159 DALYs)	% of system total	79%	2%	18%	0.5%
	% of stage total	- 63% steel production - 17% PET production	- 77% transforming steel - 12% non-ferro cast work - 6% zinc coating	- 51% powder coating - 18% welding - 12% machinery - 11% compressed air	
Solid waste (69 kg)	% of system total	20%	0.5%	8%	71%
	% of stage total	- 88% steel production - 5.5% copper production - 3% aluminum fabrication	- 91% transforming steel - 7% non-ferro cast work	- 44% powder coating - 15% welding - 11% machinery - 9% compressed air	
Transportation (49 tkm)	% of system total	36%	9%	47%	8%
Water consumption (1570 kg)	% of system total	98%	0%	2%	0%

1 'Transportation' is not an impact category per se and related environmental burdens were accounted for within the five preceding categories
2 According to IISI data on "Steel, section, EAF route", 10 MJ (LHV) of primary energy is consumed to produce 1 kg of 100% recycled steel
3 Meeting note; Steelcase Inc.; Grand Rapids, MI; August 27, 2003
4 According to ETH-ESU data on "Zinc coating S"; Zurich, Switzerland; 1996
5 Meeting note; Steelcase Inc.; Grand Rapids, MI; August 27, 2003
6 U.S. Environmental Protection Agency; Municipal Solid Waste in the United States; Washington D.C., USA; October 2003

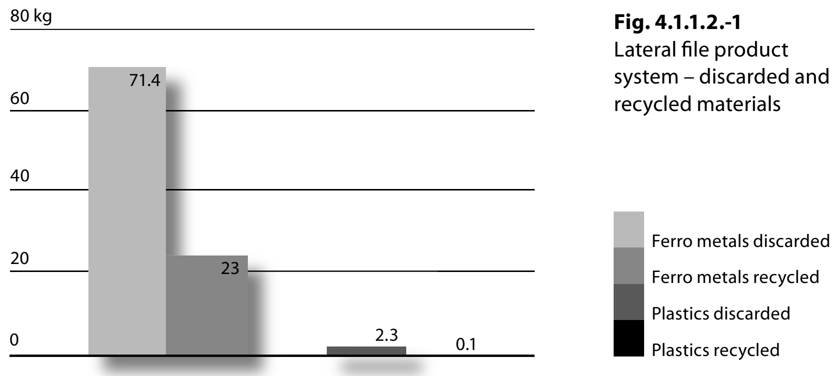


Fig. 4.1.1.2.-1
Lateral file product system – discarded and recycled materials

management system in place, Steelcase products are assumed to enter the standard U.S. waste management process at the end of their useful lives.

As a consequence, and as shown in Fig. 4.1.1.2.-1, 23 kg in ferro metals and 0.1 kg in plastic materials are ultimately recycled out of a total of 71.4 kg and 3.3 kg respectively.[1] The difference in ferro metals (48.4 kg) and plastics (3.2 kg) is either landfilled, incinerated, or directed towards unknown waste treatment.

With respect to end-of-life waste management, it becomes apparent that a clear distinction has to be made between the terms 'recycled content', 'recycability', and 'actual materials recycled'. As demonstrated with the lateral file product system, closing the loop in terms of materials is essential to the provision of recycled materials at the front-end of any product manufacturing process. For the lateral file product system and under average U.S. waste management conditions, however, about 75% of recyclable materials contained in manufacturing- and EOL scrap/waste combined is practically lost.

4.1.1.3. Lateral file product system conclusions

Environmental impacts for the lateral file product system can be identified across all life cycle stages. For the material production stage, the usage of steel as the main product constituent (98% of product system weight) is responsible for most of the environmental impacts. This is due to both the total amount of steel applied in the product system (68.8 kg) and the nature of steel manufacturing processes for hot- and cold rolled steel. Substantial environmental burdens particularly with respect to acidification and criteria pollutants are also caused by the production of PET (polyethylene terephthalate) as a precursor to thin-film powder used in powder coating processes. In terms of solid waste, copper- and aluminum production lead to notable effects especially considering their small fraction of the product system's total weight (0.1%).

The supplier stage shows only a small effect on total product system environmental burdens, however, its transportation intensity is comparatively high.

Regarding the Steelcase stage the majority of environmental impacts (99%) is related to electricity generation, of which 85% is used for powder coating, welding, and compressed air.

The end-of-life stage is negligible in terms of environmental burdens except for solid waste, where it contributes by far the most. This is mainly due to overall low recycling rates achieved throughout the U.S. municipal waste management system.

According to the study results for the lateral file product system, the following areas for environmental improvements can be identified:

- Overall product weight and amount of materials, especially steel used in product system
- Recycled content of steel used in product system
- Electricity consumption and sourcing at Steelcase facilities
- Material- and energy efficiency of powder coating processes
- Material recovery at product end-of-life

1 Numbers include flows and treatment of manufacturing scrap/waste

4.1.2. Panel product system

4.1.2.1. Panel product system results

Energy resource consumption

The impact category 'energy resource consumption' is derived from the Ecoindicator'99 method.[1] It directly correlates environmental burdens related to a product system to the system's overall consumption of primary energy resources. In this study fossil fuels, biomass, and hydropower are accounted for.

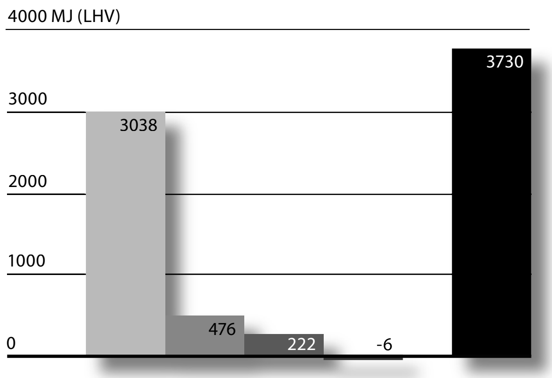


Fig. 4.1.2.1.-1
Panel product system – energy resource consumption (MJ LHV)

As shown in Fig. 4.1.2.1.-1, the total energy resource consumption for the product system amounts to 3730 MJ of lower heating value. Across all life cycle stages the material production stage accounts for most of the energy resources used (3038 MJ, 81%), followed by the supplier stage (476 MJ, 13%), the Steelcase stage (222 MJ, 6%) and the end-of-life stage (-6 MJ). The latter contributes a negative amount to the impact category due to electricity gains from plastic incineration.[2]

The major contributions to energy consumption for the material production stage stem from aluminum with 1330 MJ (44% of stage total, 36% of system total), steel with 750 MJ (25% of stage total, 20% of system total), glass fiber with 303 MJ (10% of stage total, 8% of system total), plastics (except PET) with 264 MJ (9% of stage total, 7% of system total), Polyethylene Terephthalate (PET) with 143 MJ (4.7% of stage total, 3.8% of system total), and cardboard with 114 MJ (3.8% of stage total, 3% of system total)(Fig. 4.1.2.1.-2). 'Plastics' embrace various synthetic materials of which the most influential in terms of energy resource consumption for the panel product system are the polyamides (PA) 'Nylon 6.6' and 'Nylon 6' with 160 MJ (5% of stage total) and 20 MJ (0.7% of stage total) respectively, as well as LDPE film with 71 MJ (2.3% of stage total). LDPE film and cardboard are both used as packaging materials for the final panel product components. PET is a major constituent in the production of polyester fabric (69 MJ) and thin-film powder (74 MJ), which is used in powder coating processes.

The supplier stage accounts for 476 MJ of energy resource consumption for part fabrication processes not done at Steelcase facilities and not already embedded in the material production stage. In other words, the supplier stage comprises the manufacturing of parts and subassemblies, which can be readily applied in the final panel product system (screws, fittings, plastic parts, wiring, etc.) as well as special treatments for parts originally manufactured at Steelcase and sent back to Steelcase after the treatment (surface coating processes, etc.). For the panel product system, these supplier processes are non-ferro cast work (387 MJ, 81% of stage total), zinc coating (62 MJ, 13% of stage total), injection molding (17 MJ, 3.6% of stage total), and cold transforming steel such as blanking and stamping (11 MJ, 2.2% of stage total).

Concerning the Steelcase stage, nearly 99% of the energy resource consumption is caused by the use of electricity (Electricity_TennesseeValleyAuthority) for powder coating (69 MJ, 33% of stage total), machinery (52 MJ, 26% of stage total), welding (49 MJ, 24% of stage total), compressed air (25 MJ, 12% of stage total), and individual (workplace-) fan operation (8 MJ, 4% of stage total). Compared to the lateral file product system covered in Section [4.1.1.], the panel product system consumes a higher fraction of electricity for machine operation during the Steelcase stage (11% vs. 26%). Similarly, the fraction of electricity used by workplace fans seems to be twice as high concerning the manufacturing of the panel product system than it is with the lateral file product system (4% vs. 2%). In both cases the technical specifications for the fans were the same. On the contrary, the use of cooling water for the panel product system is negligible. Section [4.1.2.2.] further elaborates these differences.

By looking at the EOL stage, it becomes apparent that compared to the other three life cycle stages no major environmental impacts occur in terms of energy resource consumption.[3] Nevertheless, cardboard- and plastic incineration – by means of concurrent electricity generation – turn what would be a loss of 6.8 MJ into a gain of about 6 MJ. The original production energy for the amount of materials incinerated, however, was more than three times as high (44 MJ) than the energy ultimately recovered (12.8 MJ).

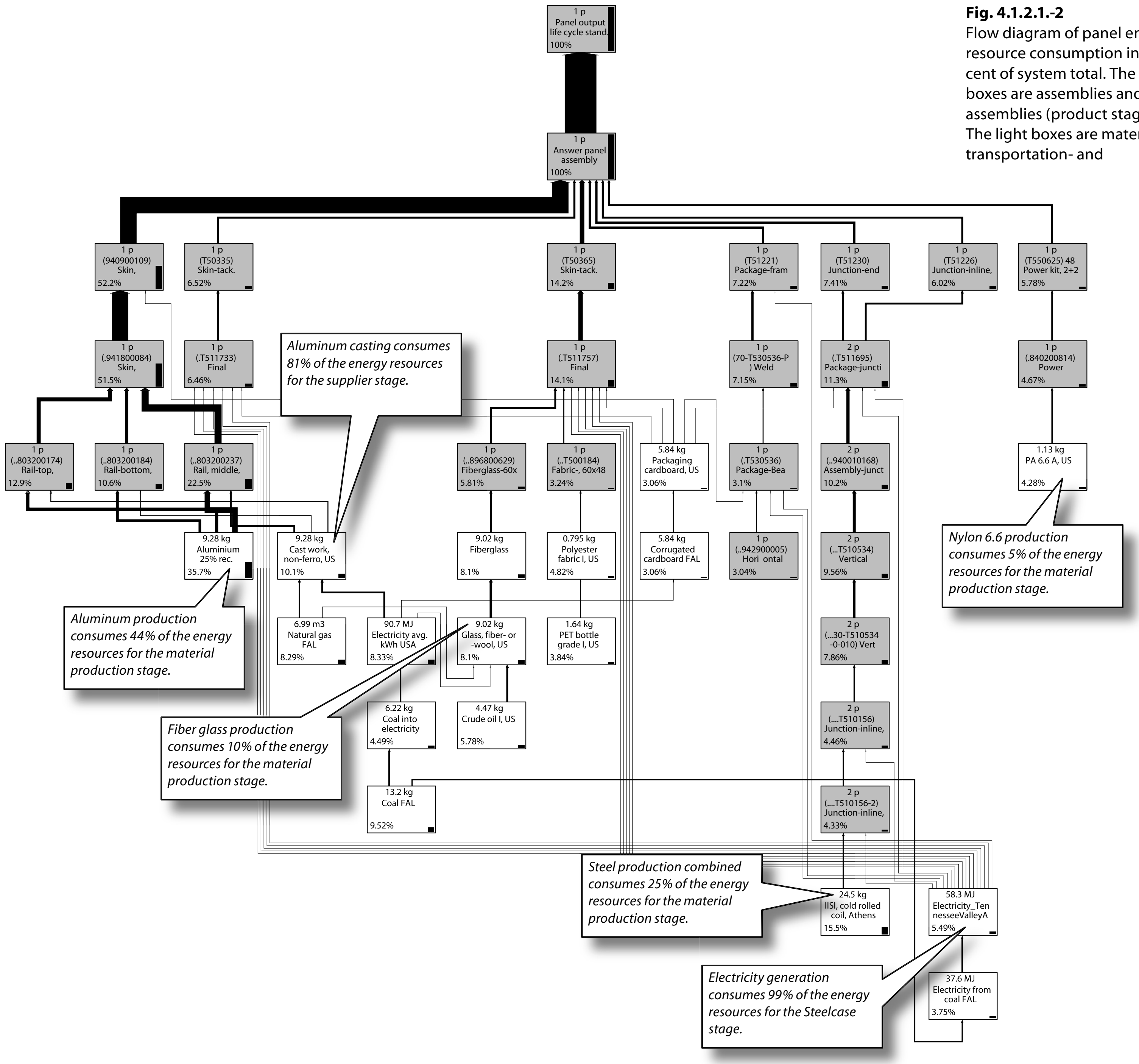


Fig. 4.1.2.1.-2
Flow diagram of panel energy resource consumption in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Goedkoop, M.; "The Ecoindicator'99", Final Report; NOH Report 9523; Pré consultants; Amersfoort, The Netherlands, 1999

2 Energy is reported in Lower Heating Values (LHV)

3 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Global warming potential

The impact category 'global warming potential' evaluates the environmental impacts in terms of global climate change due to the build-up of chemicals (greenhouse gases) that trap heat radiated back from the earth's surface, which would have otherwise passed out of the earth's atmosphere. The potency of various greenhouse gases concerning their global warming potential is expressed relative to that of carbon dioxide (CO_2 eqv.).[1] The most important greenhouse gases identified in this study are N_2O (296 kg CO_2 eqv.), methane (23 kg CO_2 eqv.), and CO_2 (1 kg CO_2 eqv.).

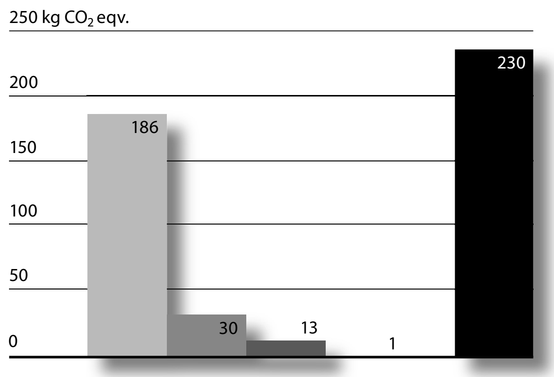


Fig. 4.1.2.1.-3
Panel product system – global warming potential (kg CO_2 eqv.)

As depicted in Fig. 4.1.2.1.-3, the global warming potential for the panel product system totals in 230 kg CO_2 eqv. and the emission distribution across all life cycle stages closely follows the one for the impact indicator 'energy resource consumption'. The material production stage accounts for 186 kg (81%), the supplier stage for 30 kg (13%), the Steelcase stage for 13 kg (6%), and the EOL stage for 1 kg (0.5%) in CO_2 equivalents (CO_2 eqv.).

As represented in Fig. 4.1.2.1.-4, the major contributors to global warming potential for the material production stage are steel with 79 kg CO_2 eqv. (42% of stage total, 34% of system total) and aluminum with 57 kg CO_2 eqv. (31% of stage total, 25% of system total) followed by cardboard used in packaging (13 kg CO_2 eqv., 6.7% of stage total), plastics (12 kg CO_2 eqv., 6.4% of stage total), glass fiber (7 kg CO_2 eqv., 3.8% of stage total), and PET for fabric- and thin-film powder fabrication (3.8 kg CO_2 eqv., 2% of stage total). For 'plastics', the most influential contributors again are 'Nylon 6.6' and 'Nylon 6' (both polyamides) with 8.7 kg CO_2 eqv. (4.7% of stage total) and 1 kg CO_2 eqv. (0.5% of stage total) respectively, as well as LDPE film with 2 kg CO_2 eqv. (1% of stage total).

The supplier stage with regard to global warming potential is dominated by non-ferro cast work with 24 kg CO_2 eqv. (80% of stage total) and zinc coating with 4.5 kg CO_2 eqv. (15% of stage total). Minor contributions come from injection molding of plastic parts (1 kg CO_2 eqv.) as well as cold transforming of steel such as stamping and blanking (0.6 kg CO_2 eqv.).

For the Steelcase stage almost 99% of global warming potential per panel product system can be related to the provision of electricity (Electricity_TennesseeValleyAuthority) utilized in powder coating (4 kg CO_2 eqv., 33% of stage total), machinery (3.1 kg CO_2 eqv., 26% of stage total), welding (2.9 kg CO_2 eqv., 24% of stage total), compressed air (1.5 kg CO_2 eqv., 12% of stage total) individual fan operation (0.5 kg CO_2 eqv., 4% of stage total), and general overhead (0.1 kg CO_2 eqv., 1% of total).

In accordance with the impact category 'energy resource consumption', only negligible environmental effects occur during the panel product system's EOL stage. The release of 1 kg CO_2 eqv. in greenhouse gases during this stage only accounts for 0.5% of the overall product system's global warming potential.[2] Credit has to be given, however, for cardboard- and paper incineration, which offsets about 0.16 kg in CO_2 eqv. otherwise discharged additionally.

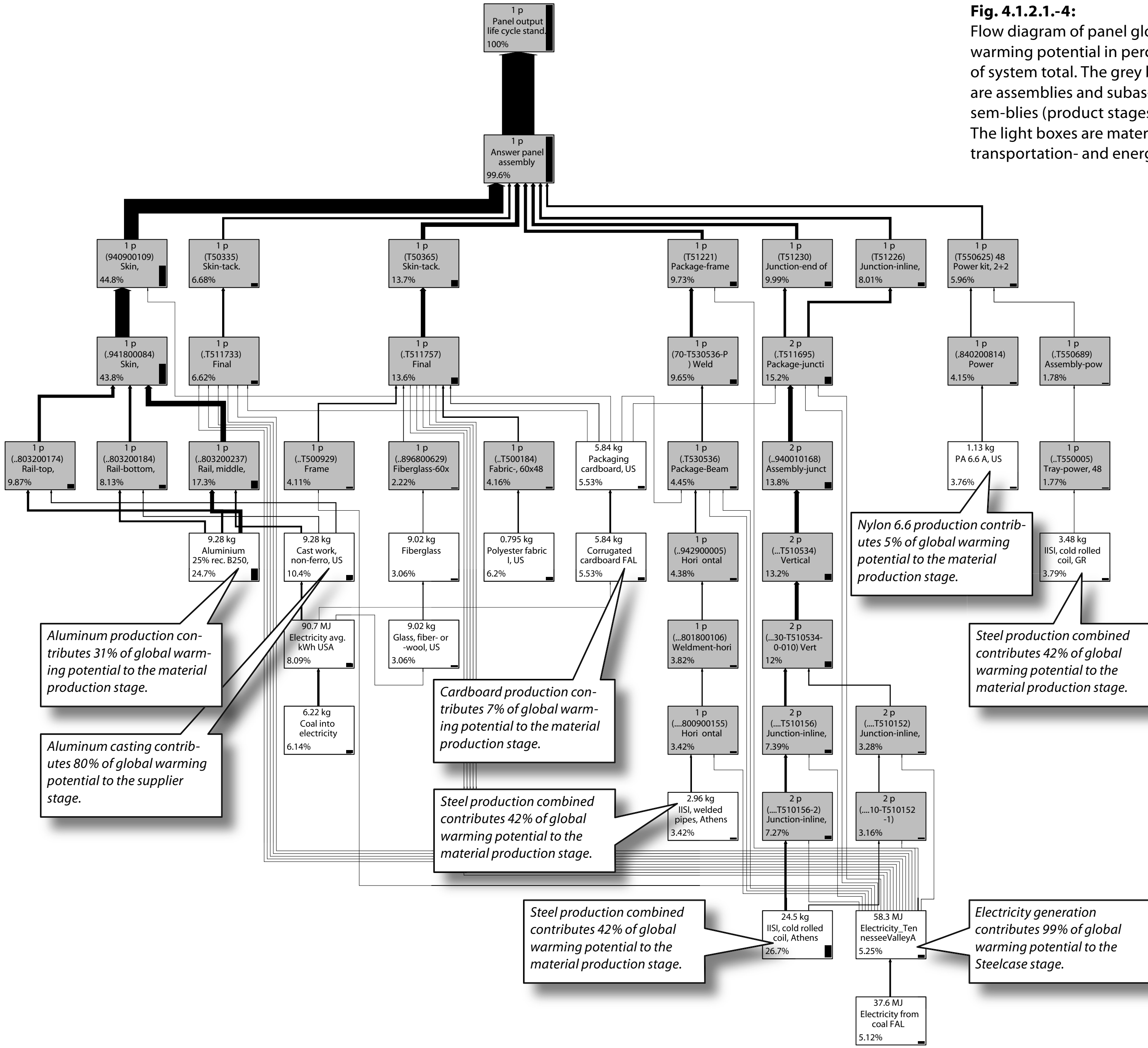


Fig. 4.1.2.1.-4:
Flow diagram of panel global warming potential in percent of system total. The grey boxes are assemblies and subassem-blies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Acidification potential

The impact category ‘acidification potential’ refers to the deposition of negatively charged ions into the environment, which leaves excess hydrogen ion concentrations (H^+) in the system. As such, acidification characterization factors are expressed in H^+ mole equivalent depositions per kg of emission from a product system.[1] The most potent substances in terms of acidification potential considered in this impact category are ammonia (95.5 H^+ mol eqv./kg), hydrofluoric acid (HF; 81 H^+ mol eqv./kg), nitric acid (NO; 61 H^+ mol eqv./kg), and sulfur dioxide (SO_2; 50.1 H^+ mol eqv./kg).

Fig. 4.1.2.1.-5
Panel product system – acidification potential (H^+ mol eqv.)

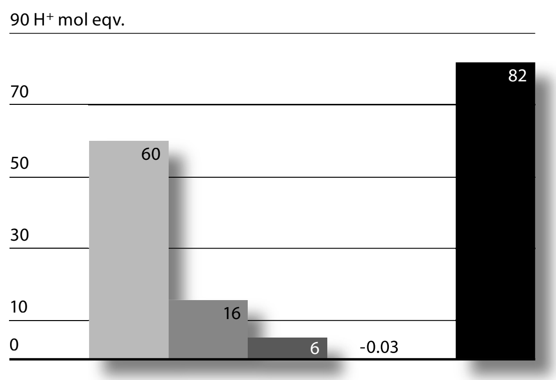


Fig. 4.1.2.1.-5 illustrates the life cycle profile for the panel product system’s acidification potential including the system’s total of 82 H^+ mol eqv. The individual contributions for the four different life cycle stages are 60 H^+ mol eqv. (73%) for the material production stage, 16 H^+ mol eqv. (20%) for the supplier stage, 6 H^+ mol eqv. (7.3%) for the Steelcase stage, and close to zero for the EOL stage. The slightly negative value for the latter is caused by energy recovery during cardboard- and plastic incineration.

Similar to the impact categories addressed earlier, the material production stage is the most dominant stage with regard to the product system’s total acidification potential. As shown in Fig. 4.1.2.1.-6, the largest contributions to this stage are caused by aluminum- (24.3 H^+ mol eqv., 41% of stage total, 30% of system total) and steel fabrication (9 H^+ mol eqv., 15% of stage total, 11% of system total), followed by the manufacturing of cardboard (5.8 H^+ mol eqv., 9.7% of stage total), plastics (5.8 H^+ mol eqv., 9.6% of stage total), glass fiber (5.6 H^+ mol eqv., 9% of stage total), and PET (3.5 H^+ mol eqv., 6% of stage total).

The supplier stage accounts for 16 H^+ mol eqv. in acidification potential of which the majority is contributed by non-ferro cast work (14 H^+ mol eqv., 85% of stage total) and zinc coating (1.6 H^+ mol eqv., 10% of stage total). Minor contributions come from injection molding (0.5 H^+ mol eqv.) and cold transforming steel (0.3 H^+ mol eqv.).

Concerning the Steelcase stage, 99% of the stage related acidification potential come from electricity usage (Electricity_TennesseeValleyAuthority) for powder coating (1.9 H^+ mol eqv., 33% of stage total), machinery (1.5 H^+ mol eqv., 26% of stage total), welding (1.4 H^+ mol eqv., 24% of stage total), compressed air (0.7 H^+ mol eqv., 12% of stage total), and workplace fan operation (0.2 H^+ mol eqv., 4% of stage total). Unlike the impact indicator ‘energy resource consumption’, the supplier stage shows an unexpectedly high acidification potential compared to the Steelcase stage, which is due mainly to the relatively high acidification potential for aluminum casting.[2] This is true despite the fact that the ‘Electricity_TennesseeValleyAuthority’ utility system harnesses just about half the fraction of hydropower (5.6%) than the average U.S. electricity generation scenario does (10%).[3] The panel product system evaluation is based on Steelcase operations using electricity from the ‘Electricity_TennesseeValleyAuthority’ utility system, whereas activities outside of Steelcase use electricity from the average U.S. grid. The application of 16 grams of copper (0.03% of total system weight) within the product system’s electrical receptacles contributes 1.2% to the stage total acidification potential (0.9% of system total).

As seen before concerning the EOL stage, environmental impacts also with regard to acidification potential can be considered negligible. However, a total of -0.03 H^+ mol eqv. indicates that a small amount of conventionally generated electricity could be substituted by end-of-life incineration (below threshold and not shown in Fig. 4.1.2.1.-6). If the latter was not accounted for, the EOL stage would end up at 0.24 H^+ mol eqv. in acidification potential.[4]

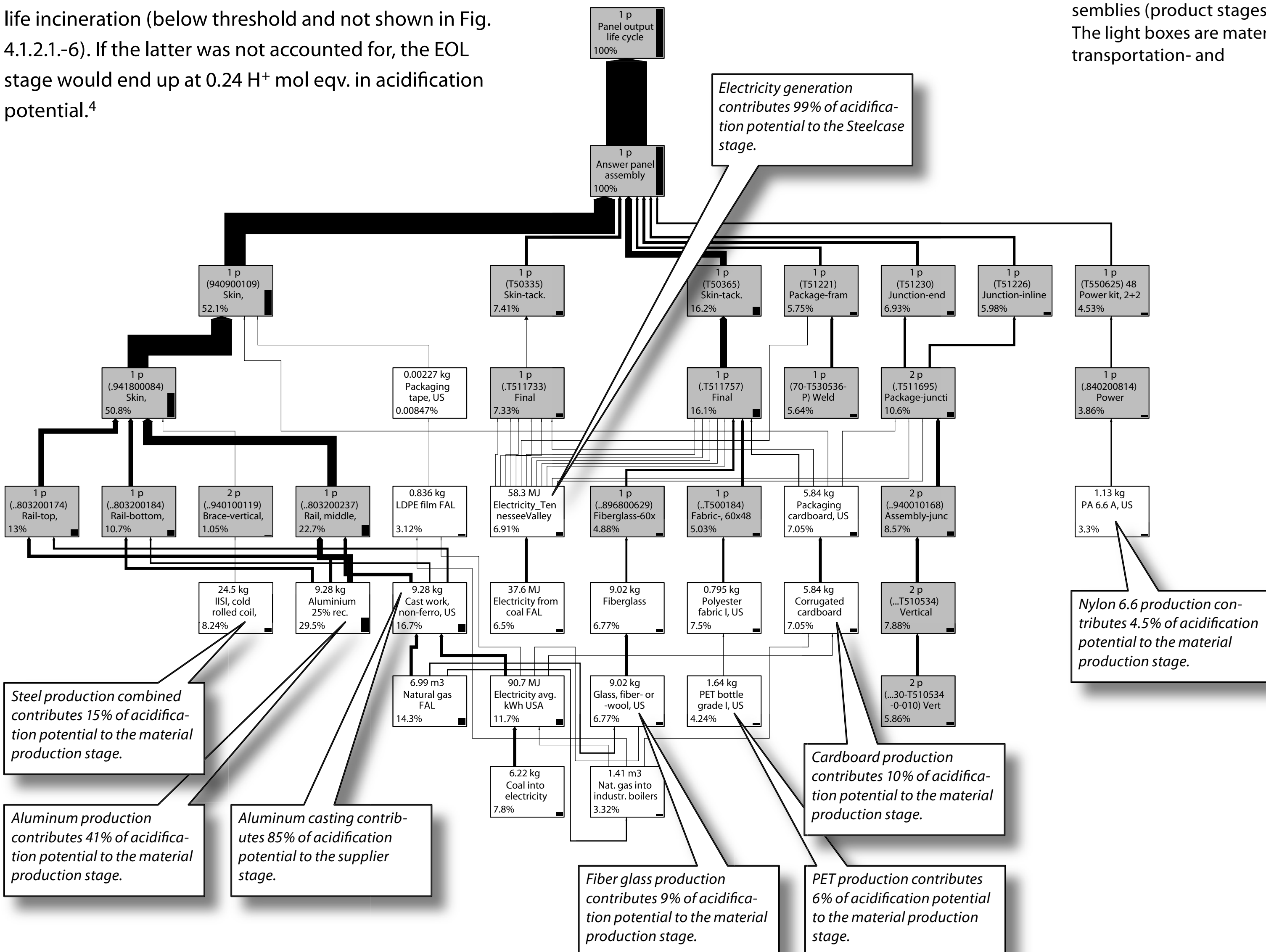


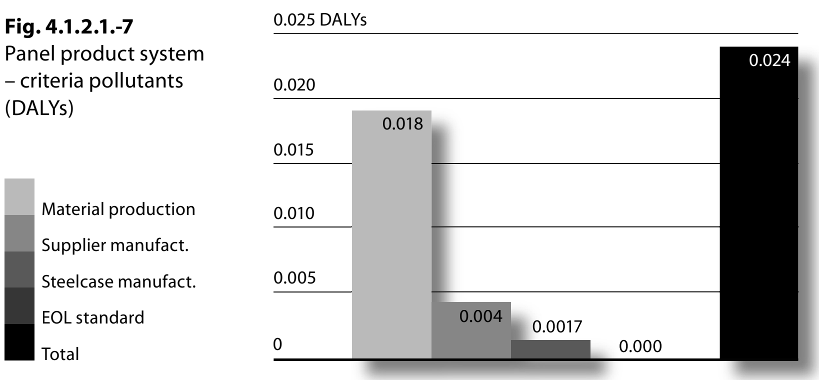
Fig. 4.1.2.1.-6
Flow diagram of panel acidification potential in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003
2 According to SimaPro Data Archive; data on “Cast work, non-ferro” (SPIN); PRé Consultants; Amersfoort; The Netherlands; 1994
3 Data for electricity generation within the ‘Electricity_TennesseeValleyAuthority’ system were derived from www.epa.gov/airmarkets/egrid/index.htm; 2002. Data for the ‘Electricity avg. kWh USA’ came from Franklin Associates; USA; 1998
4 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Criteria pollutants

The impact category 'criteria pollutants' addresses ambient particulate matter, which is strongly associated with changes in background rates of chronic and acute respiratory symptoms, as well as mortality rates. The human health effects are reported in DALYs (disability-adjusted life-years), which is a combined measure for the years of life lost and years lived with disabilities due to the exposure to criteria pollutants.[1] The most potent criteria pollutants addressed in this study are particulates ($PM_{2.5}$, PM_{10}; 0.139 DALYs/kg, 0.08345 DALYs/kg), and sulfur dioxide (SO_2; 0.0139 DALYs/kg).

Fig. 4.1.2.1.-7
Panel product system – criteria pollutants (DALYs)



The panel product system's total releases in criteria pollutants are 0.024 DALYs (Fig. 4.1.2.1.-7). Their distribution across the four life cycle stages are 0.018 DALYs (75%) for the material production stage, 0.004 DALYs (17%) for the supplier stage, 0.002 DALYs (7%) for the Steelcase stage, and practically zero for the EOL stage.

According to Fig. 4.1.2.1.-8, the material manufacturing stage - as the most influential phase for the entire panel product system also in terms of criteria pollutants - shows aluminum- and steel production as the major contributors with 0.006 DALYs (31% of stage total, 24% of system total) and 0.0043 DALYs (24% of stage total, 18% of system total), respectively. The fabrication of cardboard (0.0015 DALYs, 8.6% of stage total), plastics (0.0012 DALYs, 6.6% of stage total), glass fiber (0.0012 DALYs, 6.5% of stage total), and PET (0.0006 DALYs, 3.6% of stage total), are each causing a minor additional effect on the total. The usage of about 16 grams of copper (0.03% of system total weight) within the electrical receptacles of the panel product system causes 1.1% of the stage total criteria pollutants emitted (0.8% of system total).

Concerning the supplier stage, the majority of criteria pollutants are related to non-ferro cast work (0.0035 DALYs, 87% of stage total) and zinc coating (0.0003 DALYs, 8% of stage total). Minor environmental effects in terms of criteria pollutants can be attributed to injection molding of plastic parts (3.2% of stage total) and cold transforming steel (2% of stage total).

For the Steelcase stage electricity consumption (Electricity_TennesseeValleyAuthority) is by far the greatest cause for the release of criteria pollutants (99% of stage total). Powder coating- (0.0005 DALYs, 33% of stage total), machinery- (0.0003 DALYs, 24% of stage total), welding- (0.0003 DALYs, 24% of stage total) and compressed air processes (0.0002 DALYs, 14% of stage total) combined, account for 95% of the stage total criteria pollutant emissions (7% of system total). Minor contributors to this stage are workplace fan operation (4% of stage total) and general overhead (1% of stage total).

Once more, the EOL stage only contributes insignificant charges also with respect to the panel product system's overall amount of criteria pollutants.[2]

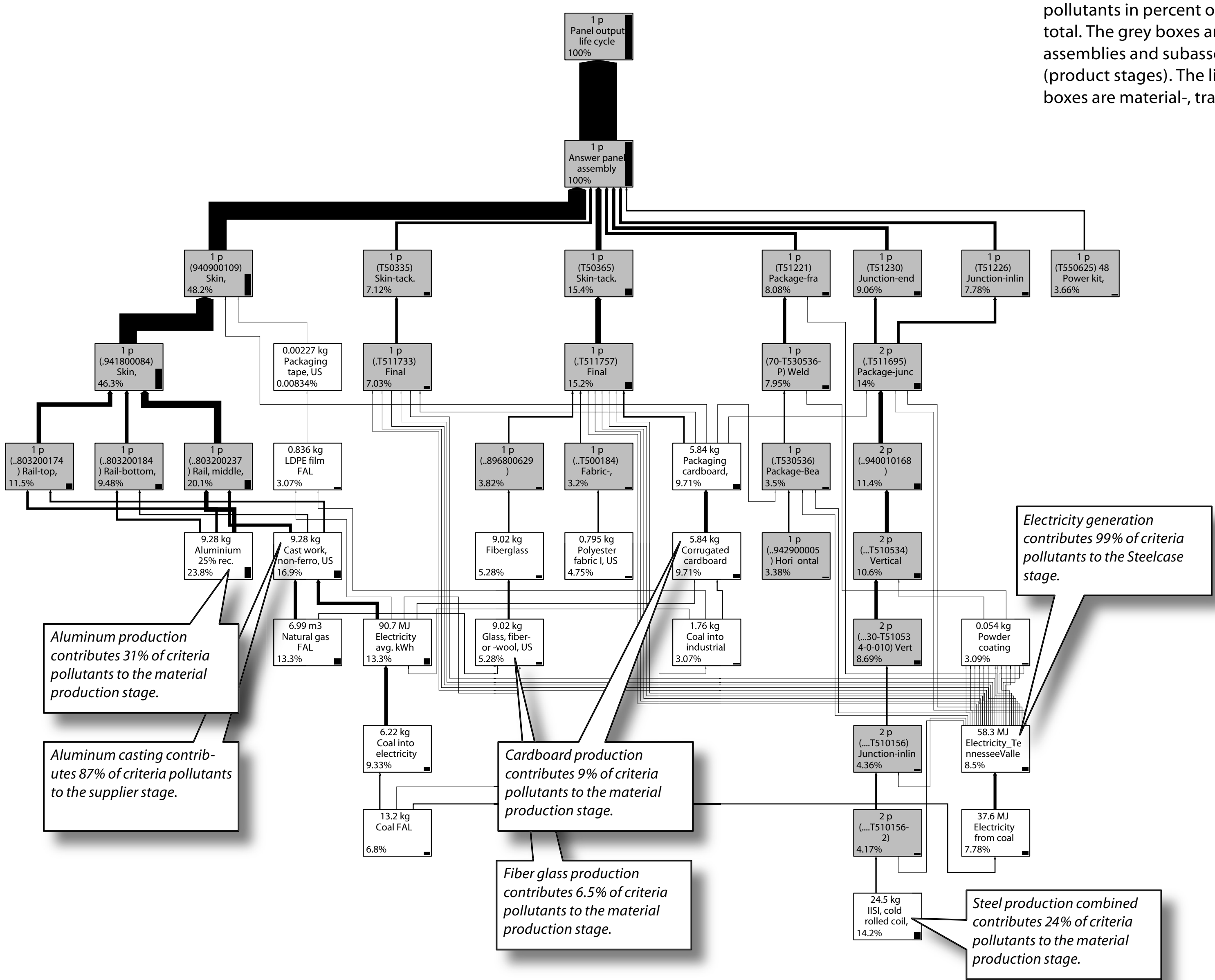


Fig. 4.1.2.1.-8
Flow diagram of panel criteria pollutants in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Solid waste (excluding recyclables)

The impact category 'solid waste' indicates environmental burdens with respect to the usage of landfill volume, the generation of non-recovered materials, and the overall material efficiency of a product system. The measure is kilograms of solid waste produced throughout the life cycle of a product system.

The generation of solid waste across all life cycle stages of the panel product system demonstrates a pattern unlike the impact categories addressed previously (Fig. 4.1.2.1.-9). Major contributions stem from the EOL stage (42 kg, 63%), followed by the material production

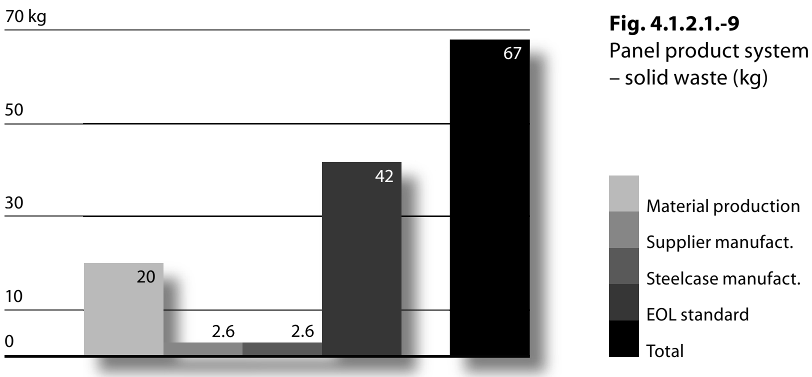


Fig. 4.1.2.1.-9
Panel product system – solid waste (kg)

stage (20 kg, 30%), the supplier stage (2.6 kg, 4%), and the Steelcase stage (2.6 kg, 4%). Concerning the Steelcase stage, it has to be pointed out that this does not include manufacturing scrap/waste, which is recycled subsequently (like steel scrap). Accordingly, solid waste for the Steelcase stage only covers waste related to off-site electricity generation as well as other energy provision activities and manufacturing waste, which is sent to waste treatment processes other than recycling.

Overall, solid waste amounts to 67 kg for the entire panel product system. As Fig. 4.1.2.1.-10 shows for values greater than 2% of the system total, major contributions to the material production stage are related to the manufacturing of aluminum (8 kg, 44% of stage total, 13% of system total), steel (5.4 kg, 28% of stage total, 8% of system total), and copper (2.7 kg, 14% of stage total, 4% of system total). For the latter it should be mentioned that the amount of copper used in the panel product system (16 grams) represents 0.03% of the total product system weight. Minor contributors to the material production stage in terms of solid waste are the fabrication of cardboard (1.7 kg, 9% of stage total), plastics (0.5 kg, 2.6% of stage total), and glass fiber (0.4 kg, 2.3% of stage total). Cardboard is used solely for packaging purposes. Glass fiber is mainly applied within the panel product system to achieve acoustical insulation.

Solid waste throughout the supplier stage is largely related to non-ferro cast work (2.4 kg, 89% of stage total), whereas injection molding of plastic parts (6.4% of stage total) as well as cold transforming steel (4% of stage total) account for most of the rest.

With regard to the Steelcase stage, solid waste predominantly stems from electricity consumption (Electricity_TennesseeValleyAuthority), which accounts for 88% of the stage total. Activities that consume the most electricity during this stage are powder coating (0.8 kg, 31% of stage total), machinery (0.6 kg, 23% of stage total), welding (0.6 kg, 23% of stage total), and compressed air (0.3 kg, 12% of stage total). Powder coating over-spray produces 0.3 kg in solid waste (12% of stage total) ultimately landfilled.[1]

The EOL stage is the biggest contributor to the generation of solid waste across the panel product system life cycle, accounting for 42 kg in solid waste.[2] This is due especially to the retirement of the whole panel product system itself as well as the handling of durable goods within the U.S. municipal waste management system.[3]

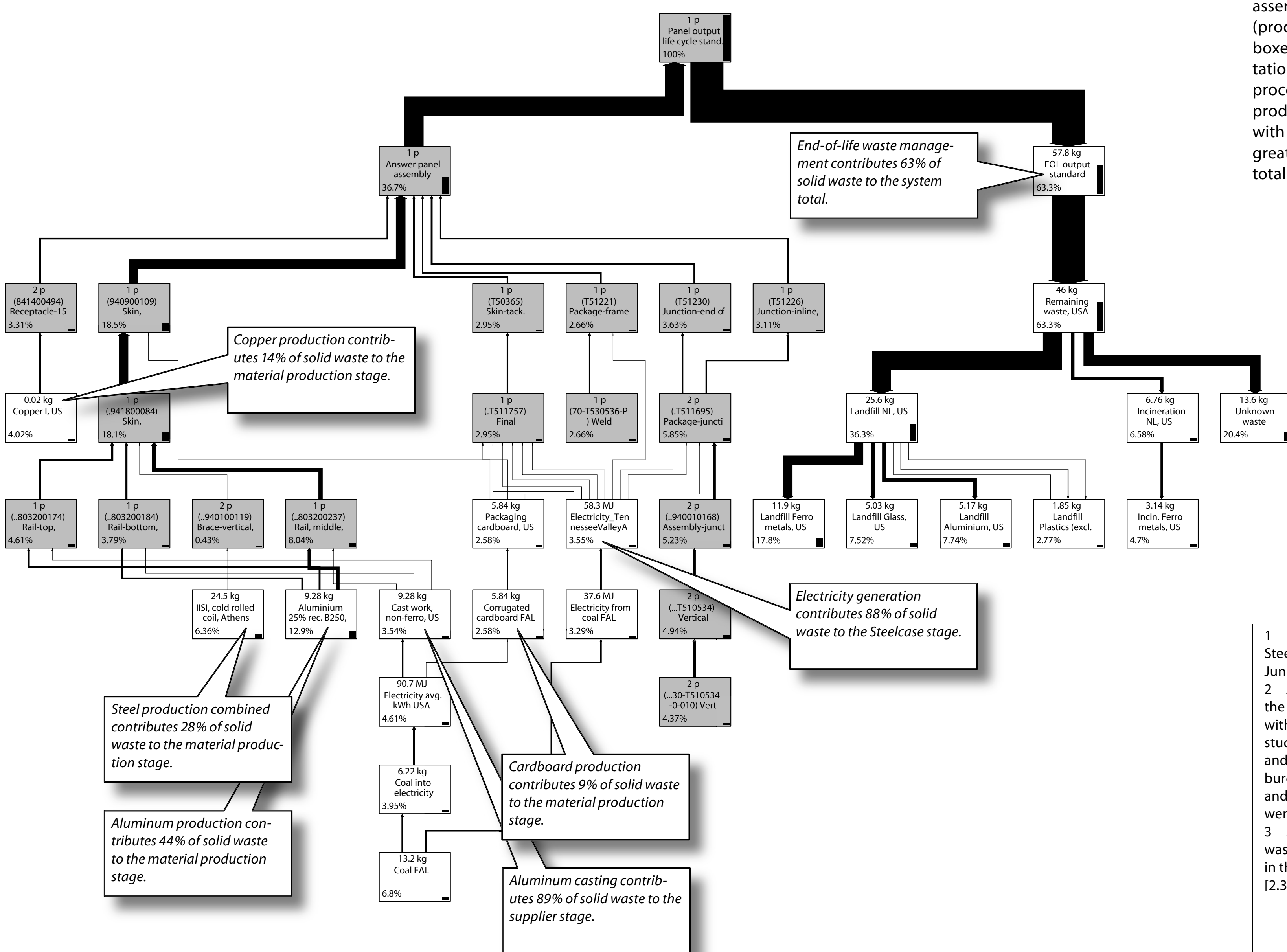


Fig. 4.1.2.1.-10
Flow diagram of panel solid waste in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 2% of the system total are shown.

1 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; June 18, 2004
2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for
3 A detailed description of the EOL waste management scenario applied in this study can be found in Section [2.3.]

Manufacturing material utilization

As shown in Table 4.1.2.1.-1, 1.8 kg of manufacturing scrap/waste is generated at Steelcase facilities (Steelcase stage), which represents 3.1% of total materials used (product weight + manufacturing scrap/waste). Since there is little or no specific information available from suppliers on how much waste is caused by manufacturing parts at their locations, default values for manufacturing scrap/waste are taken from related data sources in this study (listed under 'manufacturing processes' in Table 3.1.-2).[2] For the Steelcase stage, manufacturing scrap/waste mainly comes from steel-forming processes such as stamping and blanking (1.6 kg, 5.2% of steel total), as well as powder coating (0.28 kg, 9.6% of plastics total). Waste generation with regard to powder coating processes for the panel product system is primarily the result of low material utilization rates (60%, ratio of thin-film powder staying attached to the part and total powder applied). As a consequence, and as mentioned in Section [2.3.], the difference of 40% in thin-film powder has to be considered waste because it cannot be recycled but has to be landfilled due to color mixing.[3]

Manufacturing scrap during steel stamping and blanking processes for the panel product system is mainly associated with orifices across part surfaces (junctions and beams). In many cases manufacturing scrap/waste is also related to the overall amount of materials used in a product system. Steel manufacturing scrap generated at Steelcase facilities is completely recycled.[4] Fig. 4.1.2.1.-11 shows a graphical depiction of the two most dominant manufacturing scrap/waste streams concerning the panel product system.

Table 4.1.2.1.-1 Materials and manufacturing scrap/waste associated with panel product system

Materials	Materials used in product	Man. scrap/ waste at SC[1]		% of materials lost
Steel				
IISI, cold rolled coil	26.560	1.462	kg(r)	
IISI, hot rolled coil	0.141	0.079	kg(r)	
IISI, welded pipes	2.960	-	kg	
Steel total	*29.661*	*1.541*	*kg*	*5.2 %*
Aluminum				
Aluminium 25% rec. B250, US	9.280	N/A[2]	kg	
Aluminum total	*9.280*	-	*kg*	-
Non-ferro				
Zinc	0.630	N/A	kg	
Non-ferro total	*0.630*	-	*kg*	-
Plastics				
ABS P, US	0.020	N/A	kg	
LDPE film FAL	0.835	negligible	kg	
PA 6 I, US	0.118	N/A	kg	
PA 6.6 A, US	1.130	N/A	kg	
PE granulate average B250, US	0.032	N/A	kg	
PET bottle grade I, US	0.465	0.280	kg(l)	
PP caps FAL	0.023	N/A	kg	
Adhesive hot-melt	0.007	N/A	kg	
Plastics total	*2.630*	*0.280*	*kg*	*9.6 %*
Glass				
Fiberglass	9.020	N/A	kg	
Glass total	*9.020*	-	*kg*	-
Cardboard & paper				
Cardboard	5.840	N/A	kg	
Cardboard & paper total	*5.840*	-	*kg*	-
Product system total	***57.100***	***1.820***	***kg***	***3.1 %***

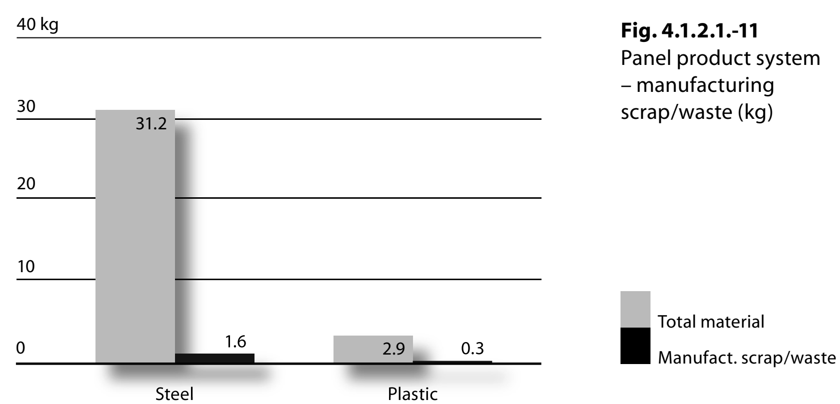


Fig. 4.1.2.1.-11 Panel product system – manufacturing scrap/waste (kg)

Transportation

As part of this study, transportation activities were recorded for processed materials, parts shipped from suppliers to Steelcase, parts and assemblies transported within and between Steelcase facilities, as well as final products delivered from Steelcase to customers. For feasibility purposes, transportation activities with respect to raw material acquisition are not reported separately here, since related data is fully embedded in the material production processes. A list of all material production processes applied in this study can be found in Section [3.2.]. Means of transportation investigated are single-unit trucks (diesel), tractor trailers (diesel), forklift operation (electric), rail transport (diesel), and waterborne vessels (fuel oil). Transportation needs are expressed in tkm (tonkilometers), that is, one tkm represents the movement of one metric ton (1 t = 1000 kg) over a distance of 1 kilometer (1 km = 1000 m) or the transport of 0.5 metric ton over 2 km, etc. Underlying data and assumptions for transportation activities are stated in Sections [2.3.] and [3.2.2.].

The greater part of transportation activities stem from the shipment of processed materials (steel, fabrics, cardboard, chemicals, etc.) to Steelcase locations (52.8 tkm, 60% of system total)(Fig. 4.1.2.1.-12). The second largest fraction in transportation is associated with hauling products and materials from Steelcase to other destinations (17.4 tkm, 20% of system total), which either means final goods to end customers (17 tkm, 19% of system total) or production related materials, like manufacturing scrap/waste, to subsequent uses or treatment processes (0.4 tkm, 1% of system total). Third in terms of transportation intensity is shipping parts and subassemblies from supplier- to Steelcase locations (15.1 tkm, 17% of system total), followed by transporting materials concerning the product's EOL to various waste management facilities (2.2 tkm, 2.5% of system total), and the movement of parts and assemblies within Steelcase operations mainly by electric forklifts (0.02 tkm). Overall, transportation activities across the panel product system life cycle total 87.8 tkm. This is equivalent to moving a single panel product system, which weighs about 58 kg, a total distance of 1514 km (946 miles).

The main means of transportation used throughout the panel product system life cycle is diesel trailers, which account for 61 tkm (70% of system total) in materials and goods shipped (Fig. 4.1.2.1.-13). Second are water-based vessels with 15 tkm (17% of system total), which mainly refers to ocean freighters for fabric transportation (14.8 tkm). Third comes shipping by rail (4.6 tkm, 5% of system total) for delivering cardboard and packaging film.

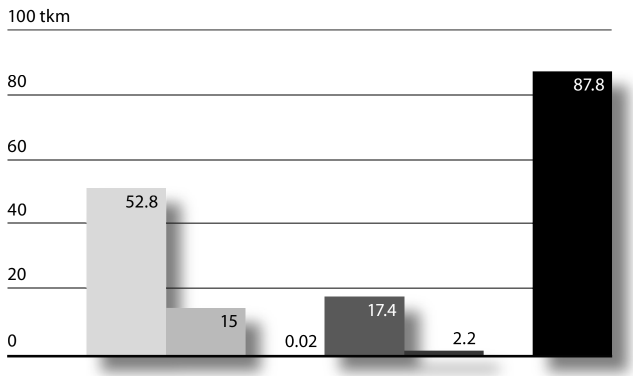


Fig. 4.1.2.1.-12
Panel product system – life cycle transportation (tkm)

Processed mat. to SC[1]
Supplier parts to SC
Within SC
SC products to others
EOL
Total

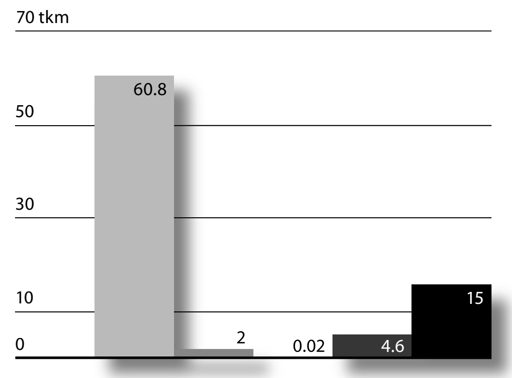


Fig. 4.1.2.1.-13
Panel product system – means of transportation (tkm)

Trailer
Single truck
Forklift
Rail
Water

1 SC = Steelcase; (r) = recycled; (l) = landfilled
2 N/A = no information available
3 Meeting note; Steelcase Inc.; Grand Rapids, MI; August 27, 2003
4 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; June 18, 2004

Specific flows

In Table 4.1.2.1.-2, various material- and energy flows are viewed more specifically in order to make them understandable from an operations point of view. Environmental impacts for the grayed items were already accounted for previously as part of the five general life cycle impact categories ‘energy resource consumption’, ‘global warming potential’, ‘acidification potential’, ‘criteria pollutants’, and ‘solid waste’. Besides these, Table 4.1.2.1.-2 introduces water consumption and overhead intensity as additional environmentally relevant measures.

Table 4.1.2.1.-2 Specific material- and energy flows associated with panel product system

Flow	Amount	
Materials in product, total	52.10	kg
Manufacturing waste @ Steelcase	1.86	kg
Water, total	1560.00	kg
Water @ Steelcase	0.51	kg
Overhead intensity @ Steelcase	14.10	m^2
Workspace lighting @ Steelcase	0.48	kWh
Individual fan operation @ Steelcase	2.12	kWh
Electricity, total	45.00	kWh
Electricity @ Steelcase	15.80	kWh
Natural gas, total	12.20	kg
Natural gas @ Steelcase	0.03	kg
Oils & lubricants @ Steelcase	<0.00	kg

As Table 4.1.2.1.-2 shows, the manufacturing of the panel product system consumes a considerable amount of fresh water (1520 kg, equal to 402 gallons) particularly for processes beyond Steelcase operations. At Steelcase itself, which in the case of the panel product system almost exclusively refers to facilities in Athens, Alabama, water consumption per panel product system totals 0.5 kg. Compared to the lateral file product system, this is much lower and is explained by the deployment of mainly mechanical presses that do not require cooling water. Furthermore, major metal works concerning stamping and blanking were outsourced to suppliers and are thus not included as water consumption in this study. Polyamid production (PA/Nylon 6.6, 797 kg, 52%), which is a major constituent (1.1 kg) of the electrical power kits utilized in the panel product system uses the greatest amount of water. Another 645 kg of water (42%) is related to steel manufacturing for beam- and junction elements. Eighty-one kg of water usage (5%) are assigned to zinc coating practices.

4.1.2.2. Panel product system discussion

This section looks at the environmental burdens related to the manufacturing of a panel product system from a systems perspective. Table 4.1.2.2.-2 gives an overview of the LCA's main results reported in Section [4.1.2.1.].

Material production stage

As the pie charts in Table 4.1.2.2.-2 show (% of system total), the material production stage is the most dominant stage with respect to both the four life cycle stages as well as the full range of impact categories except for 'solid waste'. With regard to transportation, it has to be stated that this study does not explicitly report transportation activities during raw material acquisition since those are already embedded in the material production processes and cannot be easily distinguished (see also Section [4.1.2.1.]). For the material production stage, aluminum fabrication (25% recycled content) is the single most important contributor to environmental effects across all impact categories. The panel product system employs more than 9 kg of aluminum for its 'slatwall skins' (Table 4.1.2.1.-1). In general, aluminum fabrication requires up to 200 MJ/kg in energy resource consumption for virgin material. Recycled matter needs as little as 19 MJ/kg. For comparison purposes, energy resource intensities for various manufacturing materials are shown in Table 4.1.2.2.-1.

Further environmental impacts for the material production stage are associated with the fabrication of steel, plastics (mainly Nylon 6.6, LDPE film, and PET), glass fiber, cardboard, and copper. Whereas copper renders substantial impacts mainly as solid waste, the production of all other materials mentioned causes considerable impacts for each and every of the first five impact categories in Table 4.1.2.2.-2. The amount of copper used in the panel product system, which is 0.03% of the total product weight, accounts for 4% of total system solid waste. Environmental impacts for steel utilized in the panel product system are largely related to the total quantity used (30 kg), as well as the fact that the production of one kg of steel requires about the same amount (1 kg) of coal and twenty-one kg of water.[1] For plastics, in particular, energy resource consumption is not only related to manufacturing energy, but also to energy resources embedded in the material (feedstock energy). For example, the feedstock energy for Nylon 6.6 is 50 MJ/kg, which makes up 35% of its total energy resource consumption (142 MJ/kg). 0.8 kg of LDPE film and 5.8 kg of cardboard are applied in packaging individual end-components of the panel product system before shipping. As a consequence, cardboard constitutes a considerable fraction of the total system's environmental impacts (see Table 4.1.2.2.-2).

Table 4.1.2.2.-1 Material comparisons based on energy resource consumption for production

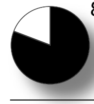
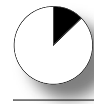
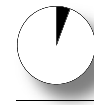
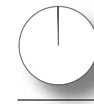
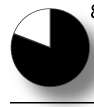
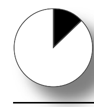
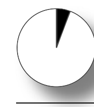
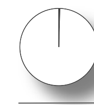
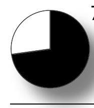
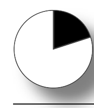
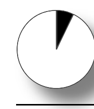
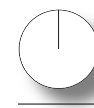
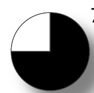
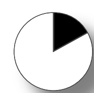
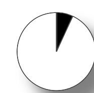
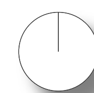
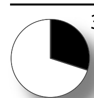
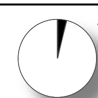
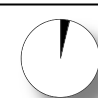
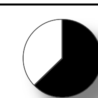
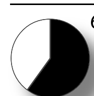
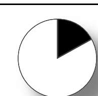
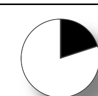
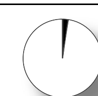
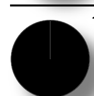
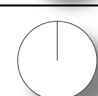
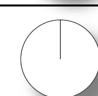
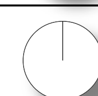
Material	Energy res. cons.	
Steel, cold rolled coil (IISI)	24	MJ/kg
Steel, hot rolled coil (IISI)	21	MJ/kg
Steel, section, EAF route, 100% rec. (IISI)	10	MJ/kg
Copper (Idemat)	92	MJ/kg
Aluminum, primary (Idemat)	192	MJ/kg
Aluminum, 80% rec. (Idemat)	19	MJ/kg
PA 6.6 (Nylon, APME)	142	MJ/kg
PET bottle grade (APME)	79	MJ/kg
PVC (APME)	57	MJ/kg
Kraft paper (Franklin)	35	MJ/kg
Kraft unbleached, 100% rec. (Franklin)	17	MJ/kg
Particleboard (BEES)	12	MJ/kg
Wood, oak (Idemat)	10	MJ/kg
Wood, silver fir (Idemat)	2	MJ/kg

Supplier manufacturing stage

The supplier stage is the second most influential of all four life cycle stages in the panel product system (Table 4.1.2.2.-2). This is largely due to a considerable amount of materials processed into parts and subassemblies at supplier operations. Casting aluminum (9.3 kg) has the greatest environmental impact for this stage, followed by zinc coating (0.63 m^2), and injection molding of plastics (1.3 kg). As materials and parts are shipped between Steelcase and supplier locations, this stage shows transportation activities (17% of system total) almost as high as those for the Steelcase stage.

1 International Iron and Steel Institute (IISI); data on Cold Rolled Coil, BF Route; August 2002

Table 4.1.2.2.-2 LCA results for manufacturing a panel product system reported for various impact categories and along all life cycle stages

Impact category		**Product life cycle stage**			
		Material production	Supplier manufacturing	Steelcase manufacturing	End-of-life
Energy resource consumption (3730 MJ LHV)	% of system total	 81%	 13%	 6%	 -0.2%
	% of stage total	- 44% aluminum fabrication - 25% steel production - 10% glass fiber production - 9% plastics production (excl. PET)	- 81% non-ferro cast work - 13% zinc coating - 3.6% injection molding	- 33% powder coating - 26% machinery - 24% welding - 12% compressed air	
Global warming potential (230 kg CO_2 eqv.)	% of system total	 81%	 13%	 6%	 0.5%
	% of stage total	- 34% steel production - 31% aluminum fabrication - 6.7% cardboard production - 6.4% plastics production (excl. PET)	- 80% non-ferro cast work - 15% zinc coating - 3.3% injection molding	- 33% powder coating - 26% machinery - 24% welding - 12% compressed air	
Acidification potential (82 H^+ mol eqv.)	% of system total	 73%	 20%	 7.5%	 0%
	% of stage total	- 41% aluminum fabrication - 15% steel production - 9.7% cardboard production - 9.6% plastics production (excl. PET)	- 85% non-ferro cast work - 10% zinc coating - 3.1% injection molding	- 33% powder coating - 26% machinery - 24% welding - 12% compressed air	
Criteria pollutants (0.024 DALYs)	% of system total	 75%	 17%	 7%	 0.5%
	% of stage total	- 31% aluminum fabrication - 24% steel production - 8.6% cardboard production - 6.6% plastics production (excl. PET)	- 87% non-ferro cast work - 8% zinc coating - 3.2% injection molding	- 33% powder coating - 24% machinery - 24% welding - 14% compressed air	
Solid waste (67 kg)	% of system total	 30%	 4%	 4%	 63%
	% of stage total	- 44% aluminum fabrication - 28% steel production - 14% copper production - 9% cardboard production	- 89% non-ferro cast work - 6.4% zinc coating - 4% transforming steel	- 31% powder coating - 23% welding - 23% machinery - 12% compressed air	
Transportation (87.8 tkm)	% of system total	 60%	 17%	 20%	 2.5%
Water consumption (1520 kg)	% of system total	 100%	 0%	 0%	 0%

Steelcase manufacturing stage

Across all life cycle stages, the Steelcase stage has the third largest environmental impact for the panel product system, which consumes 16.2 kWh in electricity (Electricity_TennesseeValleyAuthority) for each panel product system delivered. Most of the electricity within the Steelcase stage is utilized for powder coating, machinery, welding, and compressed air, which together comprise 95% of environmental burdens for each impact category except 'transportation' (Table 4.1.2.2.-2). Workplace fans account for 4% in stage related electricity usage, a fraction twice as high as for the lateral file product system. In absolute numbers energy intensity for workplace fan operation for the lateral file product system equals 0.34 MJ/m^2 compared to 0.63 MJ/m^2 for the panel product system. This can be attributed to the different climates at the Steelcase Grand Rapids, Michigan, and Steelcase Athens, Alabama, facilities. The average temperature and humidity in Athens, Alabama, is higher than in Grand Rapids, Michigan, which drives individual ventilation needs up. On the contrary, the use of cooling water and related electricity consumption concerning the panel product system is almost negligible. Since most of the steel stamping- and blanking equipment at the Athens facilities are small and medium mechanical presses, they do not require cooling water. Bigger steel handling jobs necessary for manufacturing the panel product system are outsourced to suppliers.

With regard to transportation, the Steelcase stage contributes 20% (17.6 tkm) to a system total of 87.8 tkm. This is largely due to the shipment of final product components to end customers via diesel trailers. Overall, the system total transportation activities of 87.8 tkm account for 4% of the system total energy resource consumption.

End-of-life stage

As Table 4.1.2.2.-2 shows, contributions to environmental impacts during the EOL stage are negligible with regard to most of the impact categories except for 'solid waste'. Solid waste at the product system's end-of-life represents 63% of the total solid waste generated throughout the entire panel product system life cycle. This is due, above all, to the retirement of the whole panel product system during this stage. As described in Section [2.3.], U.S. data on waste management for durable goods (which comprises furniture products) as well as packaging materials report recycling rates of 28% for steel (durable goods), 0% for aluminum (durable goods), 60% for other non-ferro metals (durable goods), and 5.5% for plastics (packaging).[1] Since, as of yet, Steelcase does not have a deliberate end-of-life management system in place, Steelcase products are assumed to enter the standard U.S. waste management process at the end of their useful lives.

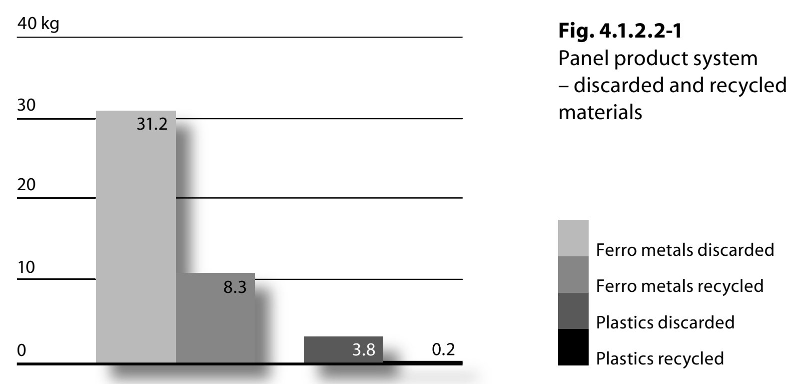


Fig. 4.1.2.2-1
Panel product system – discarded and recycled materials

As a consequence, 8.3 kg in ferro metals and 0.2 kg in plastics are ultimately recycled out of a total of 31.2 kg and 3.8 kg respectively (Fig. 4.1.2.2-1).[2] The remainders

1 U.S. Environmental Protection Agency; Municipal Solid Waste in the United States; Washington D.C., USA; October 2003
2 Numbers include flows and treatment of manufacturing scrap/waste

in ferro metals (22.9 kg) and plastics (3.6 kg) are either landfilled, incinerated, or fed into unknown waste treatment processes.

At this point it becomes apparent that the terms 'recycled content', 'recycability', and 'recycled materials' should not be confused and that a clear distinction has to be made between them in order to accurately represent product related life-cycle facts. For example, 'recycled content' for the original product system does not necessarily imply that the related materials can and will be properly recycled at the product's end of life. Also, 'recycability' does not reveal anything about whether the original product system contains recycled materials or whether material recycling takes place at the product system's end of life. Similarly, 'recycled materials' during the end-of-life stage of a product system do not automatically imply that recycled materials were a constituent of the original product system. As demonstrated with both the lateral file- and the panel product systems, a combination of back-end and front-end strategies is critical in order to sufficiently close material loops. So far, 24% of manufacturing- and EOL scrap/waste combined for the panel product system is recycled, whereas 76% is lost.

4.1.2.3. Panel product system conclusions

As reported and discussed in Sections [4.1.2.1] and [4.1.2.2], environmental impacts are generated across the entire panel product system life cycle. According to the study results, the usage of aluminum (25% recycled content) for 'slatwall skins' is the main driver for the panel product system's material production stage regarding the impact categories 'energy resource consumption', 'acidification potential', 'criteria pollutants', and 'solid waste'. Also, aluminum considerably affects environmental burdens throughout the supplier manufacturing stage when the material is further treated in non-ferro casting processes. Steel is second in terms of environmental impacts for the material production stage. It comprises about 50% of the product system's total weight. For global warming potential, steel even surpasses aluminum. This is due to the fact that substantial amounts of energy for aluminum fabrication come from hydroelectric power, whereas steel production almost exclusively harnesses coal for energy provision purposes (1 kg of coal/kg of steel). As most of the panel product system is shipped as individual components to end customers, packaging needs are substantially higher than those for the lateral file product system. As a result, cardboard manufacturing ranks third in terms of environmental impacts for the material production stage. The panel product system utilizes about 1.3 times more plastic matter than the lateral file product system does (3.5 kg vs. 1.5 kg), largely for subassemblies, fabrics and packaging purposes. As mentioned in Section [4.1.2.2.], plastics in general require substantial amounts of feedstock energy for the production of virgin material. As such, plastics account for the forth largest fraction regarding the panel product system's environmental impacts throughout the material production stage. In terms of solid waste, the production of copper causes notable effects (4% of system total), despite its relative mass of only 0.03% of the total product system weight.

Various parts and subassemblies for the panel product system, which, in particular, are related to aluminum casting, surface coating, plastic injection molding, heavy duty steel forming, and electric wiring are either purchased from independent manufacturers or custom made according to Steelcase specifications. As a consequence, the supplier stage for the panel product system shows considerably higher environmental impacts than seen with the lateral file product system. Additionally, this leads to higher transportation activities as materials and parts have to be shipped from and to different locations. On the other hand, outsourcing may reduce some environmental impacts otherwise directly related to Steelcase, such as floor space occupation and cooling water demands for hydraulic presses.

Regarding the Steelcase stage, the majority of environmental impacts (99%) are related to electricity consumption for powder coating, machinery, welding, compressed air, and the operation of workplace fans. The latter raises some interesting questions about siting and design of manufacturing facilities and the influence of traditionally unattended external factors on the performance of industrial operations.

The end-of-life stage shows environmental effects only with regard to the impact categories 'energy resource consumption' and 'solid waste'. According to Table 4.1.2.2-2, most of the solid waste for the panel product system (63% of system total) is accrued during this stage, a fact that owes itself to the retirement of the entire product system as well as the overall low recycling rates reported for the U.S. municipal waste management system.

Based on the study results for the panel product system potential environmental improvements can be identified for the following areas:

- Overall product weight and amount of materials, especially aluminum and steel used in product system
- Recycled content of aluminum, plastics, and steel used in product system
- Application of galvanic coating processes as well as rare metals (such as copper)
- Variety of plastic materials including fabrics and fibers
- Packaging strategies and -material usage
- Electricity consumption and sourcing at Steelcase facilities
- Material- and energy efficiency of powder coating processes
- Supplier compliance with (Steelcase and other) environmental standards
- Material recovery at product end-of-life

4.1.3. Work surface product system
4.1.3.1. Work surface product system results

Energy resource consumption

The impact category 'energy resource consumption' is derived from the Ecoindicator'99 method.[1] It directly correlates environmental burdens related to a product system to the system's overall consumption of primary energy resources. In this study fossil fuels, biomass, and hydropower are accounted for.

Energy resource consumption for the work surface product system totals in 1520 MJ of lower heating value (Fig. 4.1.3.1.-1). The material production stage is the most energy intensive stage accounting for 1279 MJ (84%). It is followed by the Steelcase stage (158 MJ, 10%), the supplier stage (83 MJ, 5.5%), and the end-of-life (EOL) stage (1 MJ, 0.1%).[2]

The chief energy consumers for the material production stage are the production of laminates (295 MJ, 23% of stage total, 19% of system total), aluminum (290 MJ, 23% of stage total, 19% of system total), particleboard (288 MJ, 23% of stage total, 19% of system total), and steel (288 MJ, 22% of stage total, 19% of system total)(Fig. 4.1.3.1.-2). As pointed out in Sections [4.1.1.1.] and [4.1.2.1.], energy resource consumption for steel is mainly due to the use of 1 kg coal for every kg steel produced. Energy intensity for aluminum (190 MJ/kg) comes largely from electricity usage. Compared to the lateral file- and panel product systems addressed earlier, the work surface employs higher amounts of materials derived from fossil based resources, which contribute substantially to the product system's overall energy resource consumption. As such, laminates (which basically are composite materials made of kraft-paper, melamine-, and phenolic resins) as well as particleboard (which is shredded wood and resins mixed and compressed) strongly influence the environmental performance of the work surface product system as a whole. For both, laminates as well as particleboard, energy resource consumption is mainly related to the provision of resins and to a lesser degree to the "baking" of the composite materials, which requires process heat.

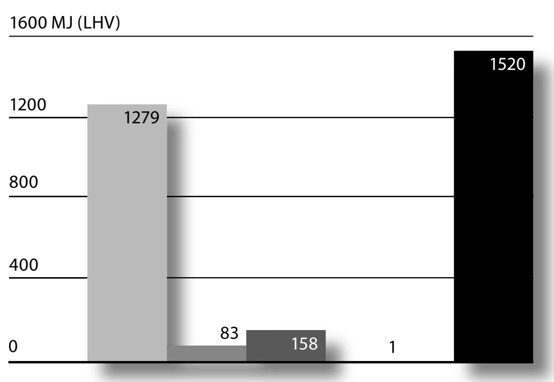


Fig. 4.1.3.1-1
Work surface product system – energy resource consumption (MJ LHV)

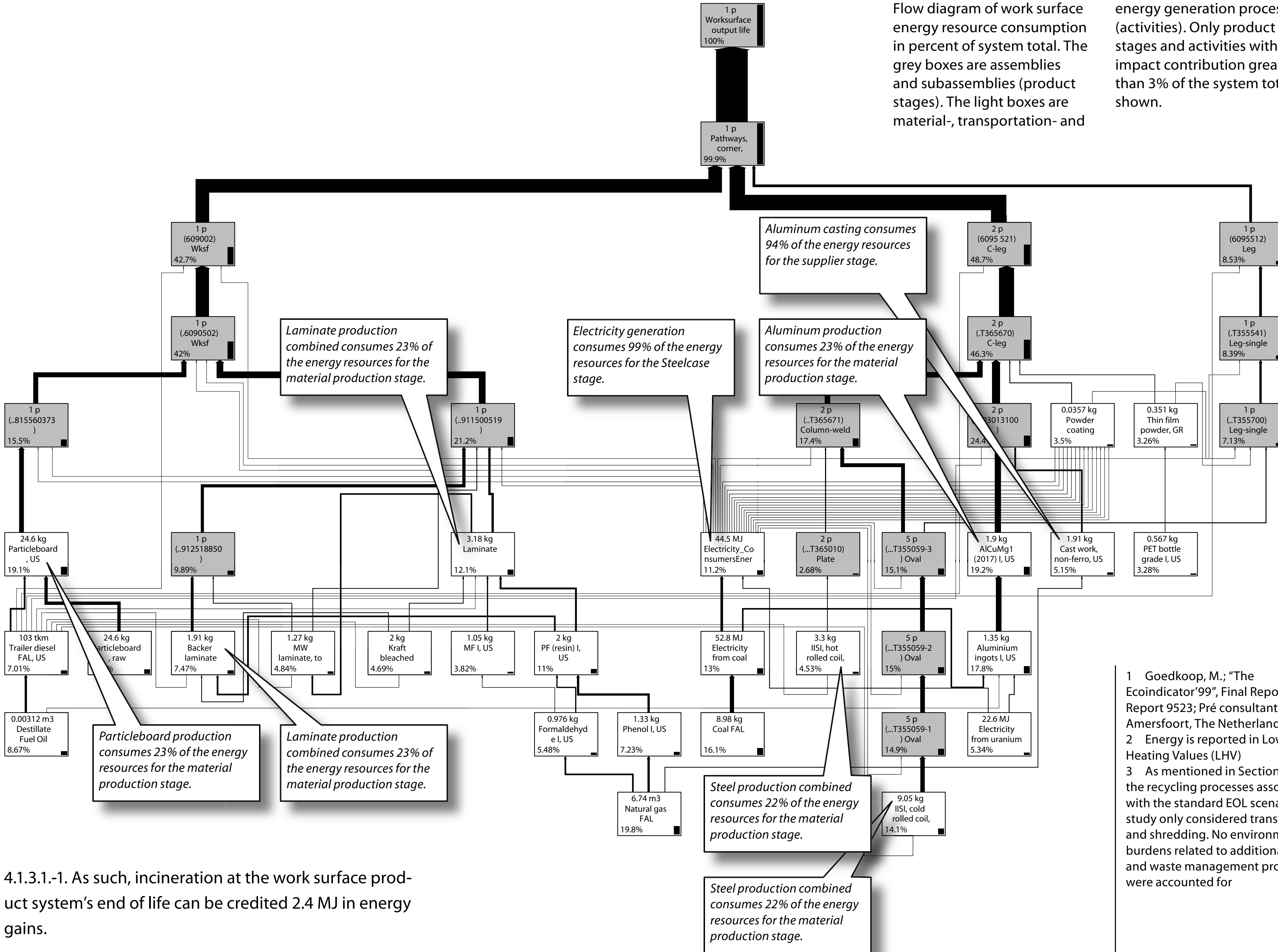
Material production
Supplier manufact.
Steelcase manufact.
EOL standard
Total

The supplier stage accounts for 83 MJ of energy resource consumption for part fabrication processes not done at Steelcase facilities and not already embedded in the material production stage. In other words, the supplier stage comprises the manufacturing of parts and subassemblies, which can be readily applied in the final work surface product system (screws, fittings, plastic parts, etc.) as well as special treatments for parts originally manufactured at Steelcase and sent back to Steelcase after the treatment (surface coating processes, etc.). With regard to the work surface product system, those supplier processes are non-ferro cast work (78 MJ, 94% of stage total) and the extrusion of PVC (3.3 MJ, 4% of stage total). The former is solely related to the casting of C-leg aluminum bases.

As seen with the product systems discussed previously, the depletion of energy resources in the Steelcase stage is almost exclusively a result of the use of electricity (Electricity_ConsumersEnergy, 99% of stage total). The major contributors to energy resource consumption are machinery (75 MJ, 36% of stage total), powder coating (49 MJ, 24% of stage total), welding (40 MJ, 20% of stage total), and compressed air (26 MJ, 13% of stage total). Combined, these four processes account for 92% of the energy resources consumed at Steelcase facilities during the manufacturing of a single work surface product system. Compared to the lateral file product system, energy resource consumption concerning cooling water- and overhead demand is low. The former is due to the fact that steel forming for the work surface product system is done mainly on roller-presses and welding is performed chiefly on MIG-welders (Gas Metal Arc Welding). The latter is largely related to high throughput rates for roller-presses. Unlike the product systems 'lateral file' and 'panel', credit is given to the work surface product system for energy recovered during the Steelcase stage. That is, incinerating 5.4 kg of particleboard manufacturing waste substitutes for 44 MJ (LHV) of conventional electricity generation. Compared to the energy intensity for particleboard manufacturing of 12 MJ/kg, this translates into an energy recovery rate of about 70% - related to what was originally invested in the production of the same amount of virgin material.

For the EOL stage, it is apparent that no significant contributions are made concerning the work surface product system's overall energy resource consumption.[3] Due to incineration with concurrent energy recovery of some of the disposed cardboard-, plastic- and wood materials, the original energy resource demand of 3.4 MJ for the EOL stage is reduced to MJ as indicated in Fig.

Fig. 4.1.3.1.-2
Flow diagram of work surface energy resource consumption in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.



4.1.3.1.-1. As such, incineration at the work surface product system's end of life can be credited 2.4 MJ in energy gains.

1 Goedkoop, M.; "The Ecoindicator'99", Final Report; NOH Report 9523; Pré consultants; Amersfoort, The Netherlands, 1999
2 Energy is reported in Lower Heating Values (LHV)
3 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Global warming potential

The impact category 'global warming potential' evaluates the environmental impacts in terms of global climate change due to the build-up of chemicals (greenhouse gases) that trap heat radiated back from the earth's surface, which would have otherwise passed through the earth's atmosphere. The potency of various greenhouse gases concerning their global warming potential is expressed relative to that of carbon dioxide (CO_2 eqv.).[1] The most powerful greenhouse gases evaluated in this impact category are N_2O (296 kg CO_2 eqv.), methane (23 kg CO_2 eqv.), and CO_2 (1 kg CO_2 eqv.).

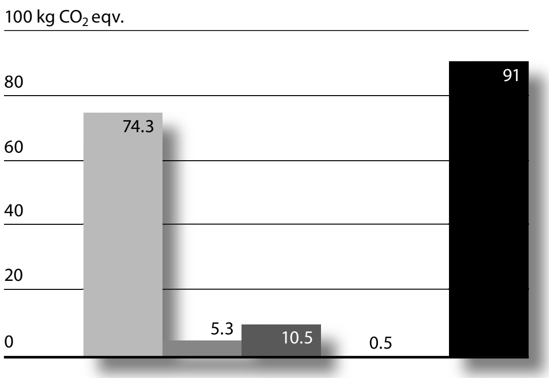


Fig. 4.1.3.1.-3
Work surface product system – global warming potential (kg CO_2 eqv.)

The global warming potential for the work surface product system reaches a total of 91 kg CO_2 eqv., which, across all life cycle stages, is distributed in a similar fashion as the impact category 'energy resource consumption' (Fig. 4.1.3.1.-3). Accordingly, the material production stage accounts for 74 kg CO_2 eqv. (81%), the supplier stage for 5 kg CO_2 eqv. (6%), the Steelcase stage for 11 kg CO_2 eqv. (12%), and the EOL stage for 1 kg CO_2 eqv. (1%).

As Fig. 4.1.3.1.-4 shows, most of the global warming potential for the material production stage is attributed to the production of steel (30 kg CO_2 eqv., 41% of stage total, 33% of system total), aluminum (16 kg CO_2 eqv., 21% of stage total, 17% of system total), particleboard (14 kg CO_2 eqv., 19% of stage total, 15% of system total), and laminates (8 kg CO_2 eqv., 11% of stage total, 9% of system total). When comparing these results to those for the impact category 'energy resource consumption', steel becomes the major contributor. This is because for steel all energy resources are turned into process energy, while for laminates and particleboard, some energy resources become actual feedstock materials. With regard to aluminum, process energy, which is mainly electricity, is partially provided by hydropower, which renders a much lower global warming potential per energy unit produced than fossil fuel based electricity generation.

Concerning the supplier stage, 94% of global warming potential comes from non-ferro cast work (5 kg CO_2 eqv.), followed by PVC extrusion with 0.2 kg CO_2 eqv. (4% of stage total). Non-ferro cast work is solely related to the production of C-leg aluminum bases.

The Steelcase stage, with respect to global warming potential, is dominated by electricity consumption (99%, Electricity_ConsumersEnergy) for machine operation (36% of stage total), powder coating (24% of stage total), welding (20% of stage total), and compressed air (13% of stage total). Minor contributions are related to overhead (4% of stage total) and individual workplace fans (2% of stage total).

Similar to the impact category 'energy resource consumption', there are only minor contributions with respect to global warming potential for the work surface product system's EOL stage (0.5 kg CO_2 eqv.).[2] Compared to the energy resources consumed by the work surface product system, offsets for global warming potential due to EOL waste incineration are disproportionately smaller (0.26 kg CO_2 eqv.). While the original amount of energy resources consumed could be reduced by 60%, there is only a drop of 35% with respect to global warming potential. This is because during incineration fossil fuels stored as feedstock materials eventually convert their global warming potential into actual greenhouse gas emissions.

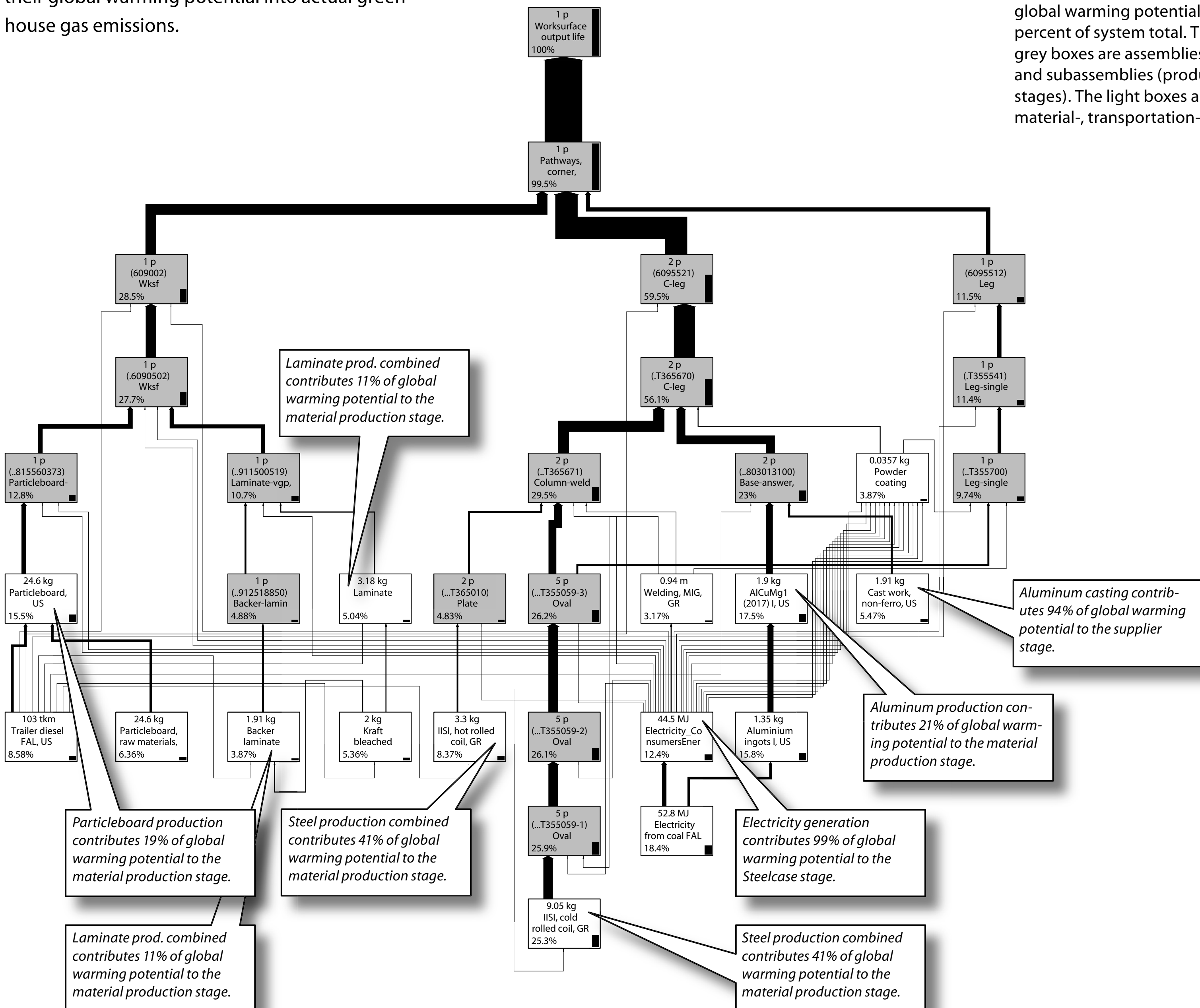


Fig. 4.1.3.1.-4:
Flow diagram of work surface global warming potential in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

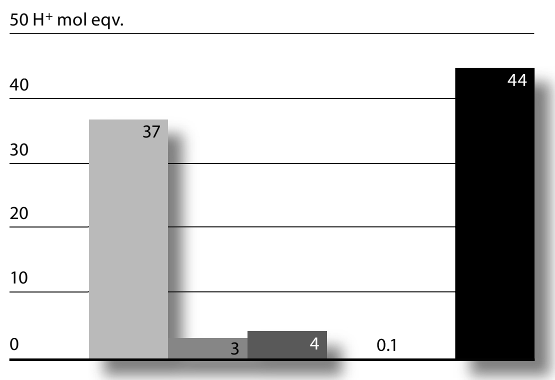
1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Acidification potential

The impact category 'acidification potential' refers to the deposition of negatively charged ions into the environment, which leaves excess hydrogen ion concentrations (H^+) in the system. As such, acidification characterization factors are expressed in H^+ mole equivalent depositions per kg of emission from a product system.[1] The most potent substances in terms of acidification potential considered in this impact category are ammonia (95.5 H^+ mol eqv./kg), hydrofluoric acid (HF; 81 H^+ mol eqv./kg), nitric acid (NO; 61 H^+ mol eqv./kg), and sulfur dioxide (SO_2; 50.1 H^+ mol eqv./kg).

Fig. 4.1.3.1.-5
Work surface product system – acidification potential (H^+ mol eqv.)



As Fig. 4.1.3.1.-5 demonstrates, the life cycle profile in terms of acidification potential for the work surface product system is dominated by the material production stage with 37 H^+ mol eqv. (84%), followed by the Steelcase stage with 4 H^+ mol eqv. (9%), the supplier stage with 3 H^+ mol eqv. (7%), and the end-of-life stage with 0,1 H^+ mol eqv. (0.2%). The acidification potential for the total work surface product system amounts to 44 H^+ mol eqv.

The largest fractions in acidification potential for the material production stage are caused by laminate manufacturing (12 H^+ mol eqv., 32% of stage total, 26% of system total), aluminum production (11 H^+ mol eqv., 29% of stage total, 24% of system total), and particleboard fabrication (6 H^+ mol eqv., 17% of stage total, 14% of system total)(Fig. 4.1.3.1.-6). The production of steel results in 3.3 H^+ mol eqv. (9% of stage total) of acidification potential, followed by plastics-, PET-, and cardboard manufacturing, which each contribute about 1.2 H^+ mol eqv. (3%) to the overall stage total of 37 H^+ mol eqv. Cardboard is solely used for packaging purposes, while PET is a precursor to thin-film powder. 'Plastics' for the work surface product system comprises various supplier parts as well as the PVC profile attached to the edge of the actual particleboard desk top.

The supplier stage accounts for 3 H^+ mol eqv. in acidification potential of which the largest part comes from non-ferro cast work (2.8 H^+ mol eqv., 94% of stage total).[2] Second is the extrusion of PVC with 0.2 H^+ mol eqv. (4% of stage total).

The most environmental impacts with respect to acidification potential for the Steelcase stage are related to electricity consumption (Electricity_ConsumersEnergy, 99% of stage total)(Fig. 4.1.3.1.-6). More specifically, the greater parts are related to utilizing electricity for running machinery (1.6 H^+ mol eqv., 31% of stage total), powder coating processes (1.5 H^+ mol eqv., 26% of stage total), welding equipment (1.2 H^+ mol eqv., 22% of stage total), and air compressors (0.8 H^+ mol eqv., 14% of stage total). About 5% of stage total acidification potential comes from overhead. Workplace fans contribute 2% to the stage total.

Similar to the end-of-life stages already addressed, environmental impacts seen here are negligible (0.1 H^+ mol eqv.).[3] Incineration processes and related energy recovery, substitute about 0.03 H^+ mol eqv. in acidification potential, which otherwise would be released through conventional electricity generation.

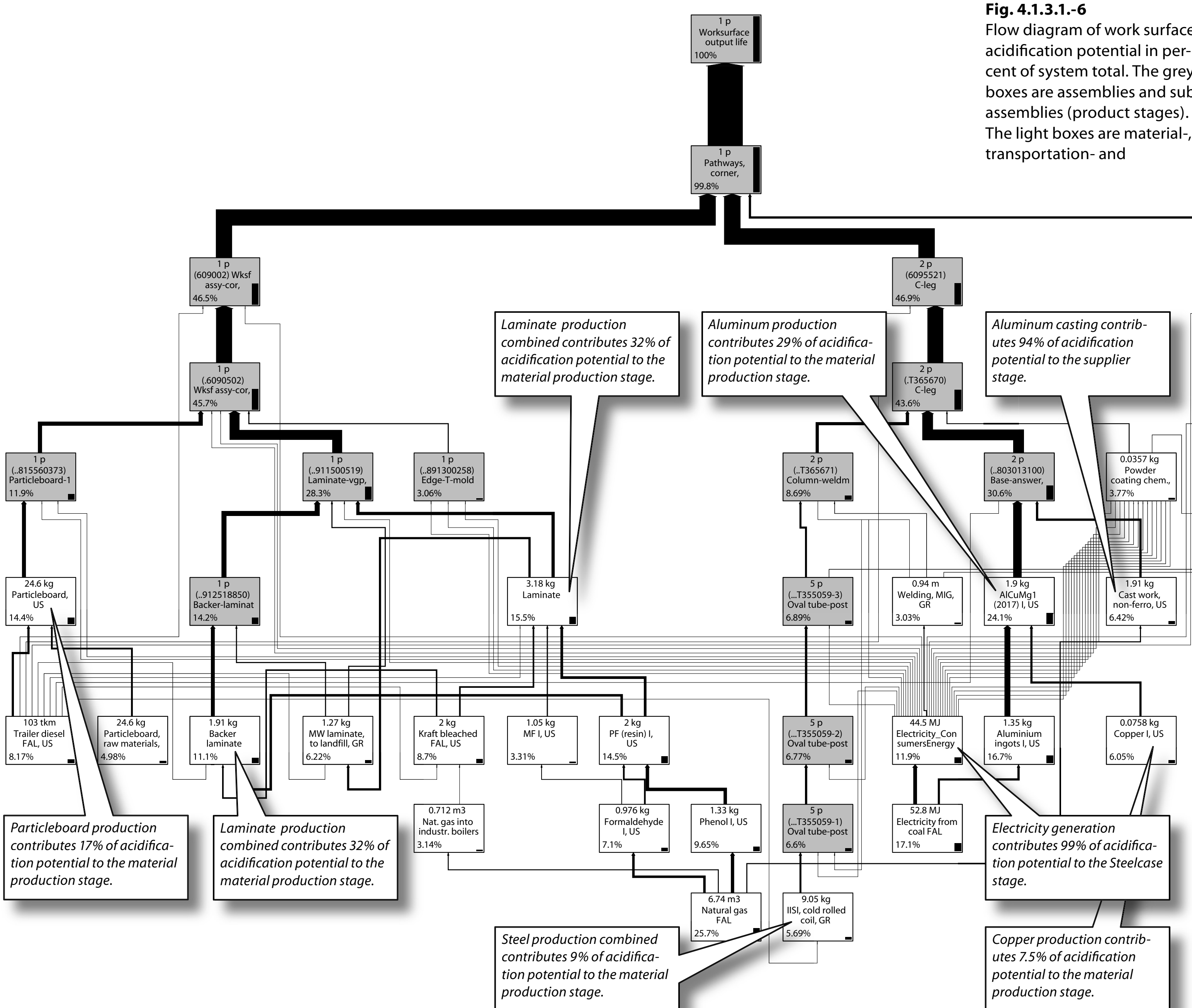


Fig. 4.1.3.1.-6
Flow diagram of work surface acidification potential in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

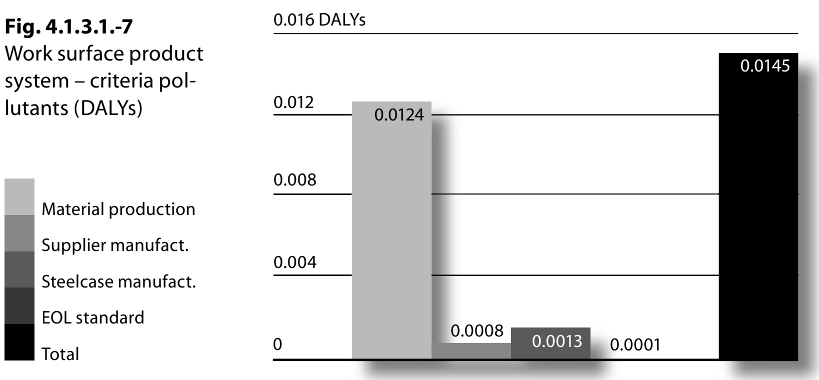
2 According to SimaPro Data Archive; data on “Cast work, non-ferro”; PRé Consultants; Amersfoort; The Netherlands; 1994

3 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Criteria pollutants

The impact category 'criteria pollutants' addresses ambient particulate matter, which is strongly associated with changes in background rates of chronic and acute respiratory symptoms, as well as mortality rates. The human health effects are reported in DALYs (disability-adjusted life-years), which is a combined measure for the years of life lost and years lived with disabilities due to the exposure to criteria pollutants.[1] The most potent criteria pollutants addressed in this impact category are particulates ($PM_{2.5}$, PM_{10}; 0.139 DALYs/kg, 0.08345 DALYs/kg), and sulfur dioxide (SO_2; 0.0139 DALYs/kg).

Fig. 4.1.3.1.-7
Work surface product system – criteria pollutants (DALYs)



Over the full life cycle of a work surface product system a total of 0.0145 DALYs in criteria pollutants is released (Fig. 4.1.3.1.-7). More specifically, 0.0124 DALYs (86%) of criteria pollutants come from the material production stage, 0.0013 DALYs (9%) from the Steelcase stage, 0.0008 DALYs (5%) from the supplier stage, and 0.0001 DALYs (1%) are attributed to the end-of-life stage.

According to Fig. 4.1.3.1.-8, the manufacturing of laminates (0.003 DALYs, 24% of stage total, 20% of system total), aluminum (0.027 DALYs, 22% of stage total, 19% of system total), steel (0.0016 DALYs, 13% of stage total, 11% of system total), and particleboard (0.0014 DALYs, 11% of stage total, 10% of system total) are the largest contributors of criteria pollutants to the work surface product system's material production stage. Smaller fractions come from plastics-, cardboard-, and PET production with 3%, 2.5%, and 2% of stage total criteria pollutants respectively. Cardboard is used exclusively for packaging purposes of individual components of the work surface product system. PET production is related to 560 grams of thin-film powder used in powder coating processes.

For the supplier stage the largest fraction of criteria pollutants is attributed to non-ferro cast work (0.0007 DALYs, 95% of stage total), followed by the extrusion of PVC (4% of stage total).

The Steelcase stage accounts for 0.0013 DALYs of criteria pollutants, which are mainly related to the utilization of electricity (Electricity_ConsumersEnergy) for machinery (0.0006 DALYs, 37% of stage total), powder coating (0.0004 DALYs, 23% of stage total), welding (0.0003 DALYs, 20% stage total), and compressed air (0.0002 DALYs, 13% of stage total). Combined, these four activities account for 93% of the total amount of criteria pollutants for the Steelcase stage. The remainder is related to overhead (5% of stage total) and the operation of individual workplace fans (2% of stage total).

Again, with respect to the EOL stage, only minor impacts can be reported in terms of criteria pollutants. Waste incineration during this stage, combined with electricity generation, lowers the total amount of pollutants from what was originally 4.8 E-5 DALYs to 2.1 E-5 DALYs.

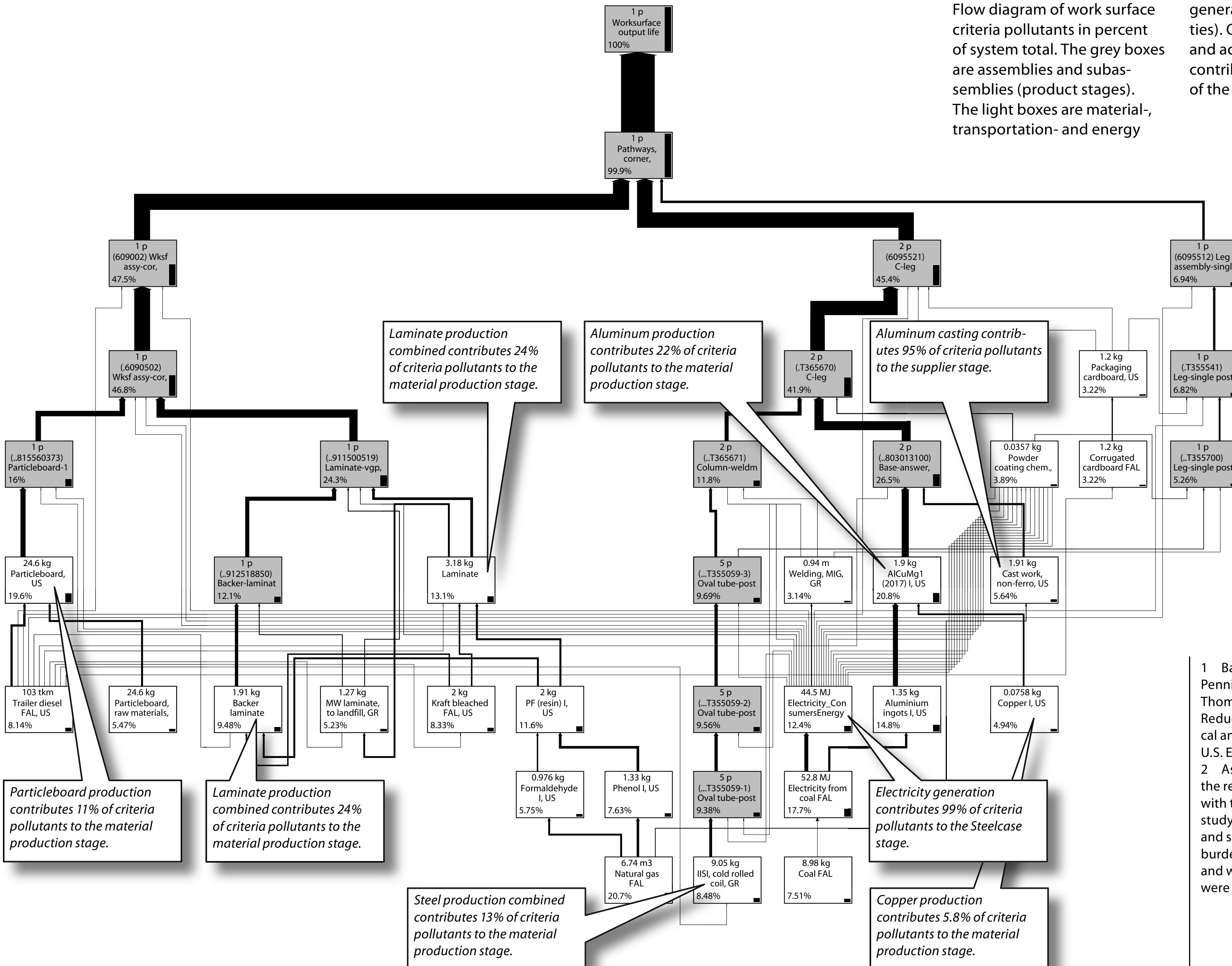


Fig. 4.1.3.1.-8
Flow diagram of work surface criteria pollutants in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 3% of the system total are shown.

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for

Solid waste (excluding recyclables)

The impact category 'solid waste' indicates environmental burdens with respect to the usage of landfill volume, the generation of non-recovered materials, and the overall material efficiency of a product system. The measure is kilograms of solid waste produced throughout the life cycle of a product system.

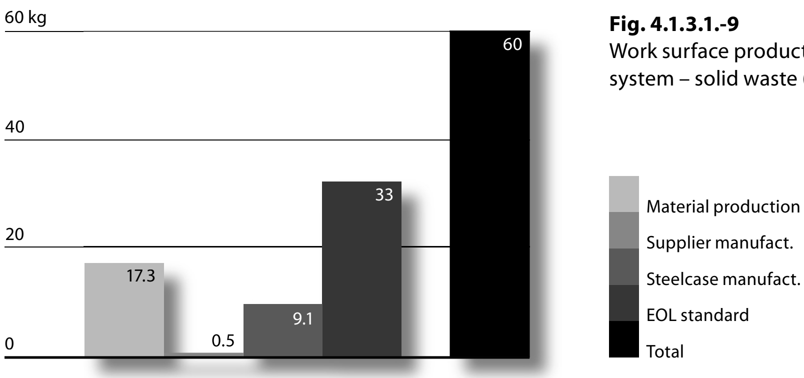


Fig. 4.1.3.1.-9
Work surface product system – solid waste (kg)

Across all life cycle stages of the work surface product system the end-of-life stage generates the most solid waste with 33 kg (55%), followed by the material production stage with 17 kg (29%), the Steelcase stage with 9.1 kg (15%), and the supplier stage with 0.5 kg (1%)(Fig. 4.1.2.1-9). This results in a total of 60 kg of solid waste for the entire work surface product system. With regard to the Steelcase stage, it has to be mentioned that this does not include manufacturing scrap/waste, which is recycled subsequently (e. g. steel scrap). Accordingly, solid waste for the Steelcase stage only covers waste related to off-site electricity generation and other energy provision activities, as well as manufacturing waste that is sent to waste treatment processes other than recycling.

The supplier stage contributes the smallest fraction in solid waste to the overall product system, which largely comes from aluminum casting (0.5 kg, 98% of stage total).

For the Steelcase stage, solid waste generation is related to electricity consumption (2.1 kg, 27% of stage total), as well as manufacturing waste from powder coating and particleboard cutting – including laminates (5.7 kg, 71% of stage total). Particleboard- and laminate waste is primarily due to the curved design of the actual work surface top that contrasts the rectangular shape of the raw materials used (boards and sheets). As a consequence, about 23% of both the initial particleboard- and laminate materials end up in waste incineration processes.[1] As described in greater detail in Section 'Manufacturing Material Utilization' below, over-spray material from powder coating is landfilled.[1] Electricity consumption (Electricity_ConsumersEnergy) and related solid waste generation are mainly associated with machinery operation (0.6 kg, 8% of stage total), powder coating (0.6 kg, 8% of stage total), welding (0.5 kg, 6% of stage total), and compressed air (0.3 kg, 4% of stage total).

By far the biggest contributions to solid waste emissions happen during the work surface product system's end-of-life stage.[2] On average, 33 kg of the product system's total material weight of 40 kg are expected to be turned into solid waste. This is particularly due to the waste handling strategies for durable goods practiced within the U.S. municipal waste management system.[3]

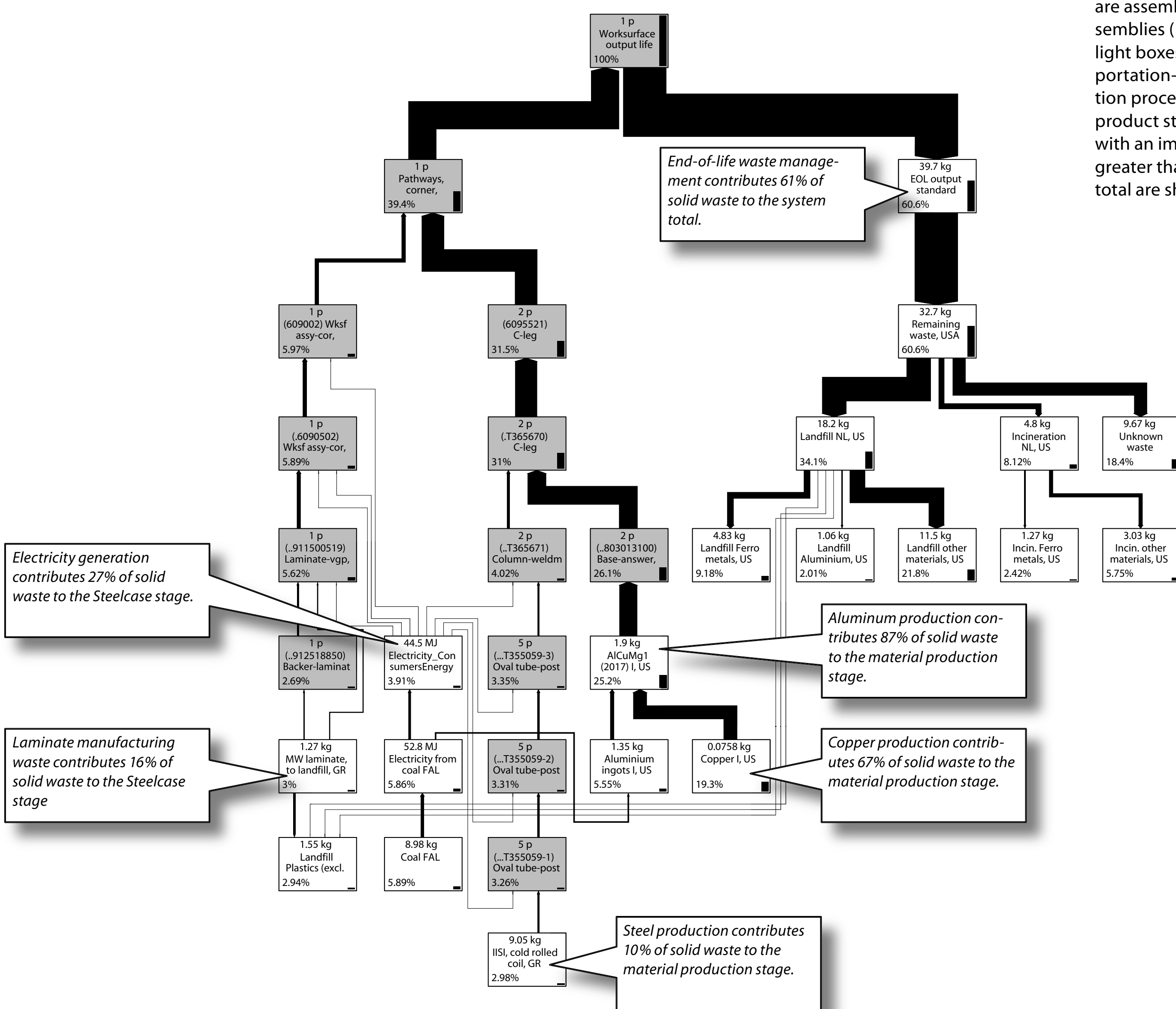


Fig. 4.1.3.1.-10
Flow diagram of work surface solid waste in percent of system total. The grey boxes are assemblies and subassemblies (product stages). The light boxes are material-, transportation- and energy generation processes (activities). Only product stages and activities with an impact contribution greater than 2% of the system total are shown.

1 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; June 18, 2004
2 As mentioned in Section [3.2.4.], the recycling processes associated with the standard EOL scenario for this study only considered transportation and shredding. No environmental burdens related to additional scrap and waste management procedures were accounted for
3 A detailed description of the EOL waste management scenario applied in this study can be found in Section [2.3.]

Manufacturing material utilization

7.2 kg of manufacturing scrap/waste is generated at Steelcase facilities (Steelcase stage), which represents 15.6% of total materials used (product weight + manufacturing scrap/waste)(Table 4.1.3.1.-1). Since there is little or no specific information available from suppliers on how much waste is caused by manufacturing parts at their operations, default values for manufacturing scrap/waste are taken from related data sources in this study (listed under 'manufacturing processes' in Table 3.1.-2).[3] Unlike the lateral file- and panel product systems, most manufacturing waste for the work surface product system is related to fabricating the actual desk top rather than steel forming processes. As such, cutting the curved desk top from an initially rectangular board generates 6.7 kg in manufacturing waste (93% of total manufacturing scrap/waste). Particleboard as well as laminates, which were attached previously to particleboard cutting, are the main constituents of that waste. 0.3 kg in manufacturing scrap comes from steel stamping and -blanking, and 0.2 kg in manufacturing waste is associated with powder coating. The latter is primarily due to low material utilization rates (60%, ratio of thin-film powder staying attached to the part and total powder applied). As a result, and as stated in Section [2.3.], the difference of 40% in thin-film powder has to be considered solid waste since it cannot be recycled at this point but has to be landfilled due to the mixing of colors.[1] Steel manufacturing scrap generated at Steelcase facilities is fully recycled.[4] Fig. 4.1.3.1.-11 shows a graphical depiction of the three most dominant manufacturing scrap/waste streams related to the work surface product system.

Table 4.1.3.1.-1 Materials and manufacturing scrap/waste associated with work surface product system

Materials	Materials used in product	Man. scrap/ waste at SC[2]		% of materials lost	
Steel					
IISI, cold rolled coil	3.010	0.291	kg(r)		
IISI, welded pipes	9.040	-	kg		
Steel total	*12.14*	*0.291*	*kg*	*2.4*	*%*
Aluminum					
AlCuMg1 (2017) I, US	1.900	N/A[3]	kg		
Aluminum total	*1.900*	*-*	*kg*	*-*	
Non-ferro					
Zinc	0.019	N/A	kg		
Non-ferro total	*0.019*	*-*	*kg*	*-*	
Plastics					
LLDPE film FAL	0.001	negligible	kg		
PA 6 I, US	0.032	N/A	kg		
PA 6.6 A, US	0.001	N/A	kg		
PET bottle grade I, US	0.351	0.210	kg(l)		
PMMA beads P	0.014	N/A	kg		
PP caps FAL	0.113	N/A	kg		
PVC FAL	0.513	0.005	kg		
Plastics total	*1.024*	*0.215*	*kg*	*17.3*	*%*
Wood					
Particleboard, US	19.100	5.440	kg(i)		
Wood total	*19.100*	*5.440*	*kg*	*22.2*	*%*
Laminate					
Front-laminate	1.910	0.635	kg(i)		
Backer-laminate	1.910	0.635	kg(i)		
Laminate total	*3.820*	*1.270*	*kg*	*25.0*	*%*
Others					
Cardboard	1.200	negligible	kg		
Others total	*1.200*	*-*	*kg*	*-*	
Product system total	***39.200***	***7.220***	***kg***	***15.6***	***%***

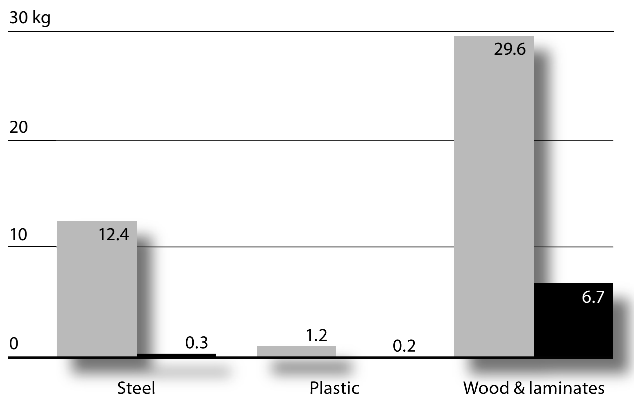


Fig. 4.1.3.1.-11 Work surface product system – manufacturing scrap/waste (kg)

Total material
Manufact. scrap/waste

Transportation

As part of this study, transportation activities were recorded for processed materials, parts shipped from suppliers to Steelcase, parts and assemblies transported within and between Steelcase facilities, as well as final products delivered from Steelcase to customers. For feasibility purposes, transportation activities with respect to raw material acquisition are not reported separately here, since related data are fully embedded in the material production processes. A list of all material production processes applied in this study can be found in Table 3.1.-2. Means of transportation investigated are single-unit trucks (diesel), tractor trailers (diesel), forklift operation (electric), rail transport (diesel), and waterborne vessels (fuel oil). Transportation needs are expressed in tkm (tonkilometers), that is, one tkm represents the movement of one metric ton (1 t = 1000 kg) over a distance of 1 kilometer (1 km = 1000 m) – or the transport of 0.5 metric tons over a distance of 2 km, etc. Underlying data and assumptions for transportation activities are stated in Sections [2.3.] and [3.2.2.].

The majority of transportation activities is related to shipping processed materials (particleboard, steel, laminates, chemicals, etc.) to Steelcase facilities (97.5 tkm, 87% of system total)(Fig. 4.1.2.1.-12). According to the study results, 79 tkm of those 97.5 tkm (81% of stage total) are attributed to shipping particleboard from Eugene, Oregon to Grand Rapids, Michigan.[5] Second in terms of transportation efforts is delivering products and materials from Steelcase to subsequent destinations (14.2 tkm, 13% of system total), which either refers to shipping final goods to end customers (12.1 tkm, 11% of system total) or production related materials, like manufacturing scrap/waste, to subsequent uses or treatment stages (2 tkm, 2% of system total). Compared to the lateral file- and panel product system, transportation of parts and subassemblies from suppliers to Steelcase facilities is much lower for the work surface product system (0.6 tkm compared to 4.4 tkm and 15 tkm respectively). This is because the work surface product system is almost exclusively manufactured in-house. With regard to the EOL stage, transportation efforts amount to 1.1 tkm (1% of system total). Across all life cycle stages, the work surface product system requires a total of 111 tkm in transportation activities. Based on the product system's overall weight of 40 kg, this is equivalent to shipping a single work surface product system a distance of 2846 km (1778 miles).

The central means of transportation used throughout the life cycle of a work surface product system is diesel trailers accounting for 103 tkm (93% of system total) in materials and goods transported (Fig. 4.1.3.1.-13). In comparison to that, further means of transportation are rather minor, which is single trucks used mainly for hauling manufacturing waste (2.7 tkm, 2.5% of system total), rail transport for hauling paper, cardboard, and plastics, and water borne vessels for shipping copper and PVC related raw materials.

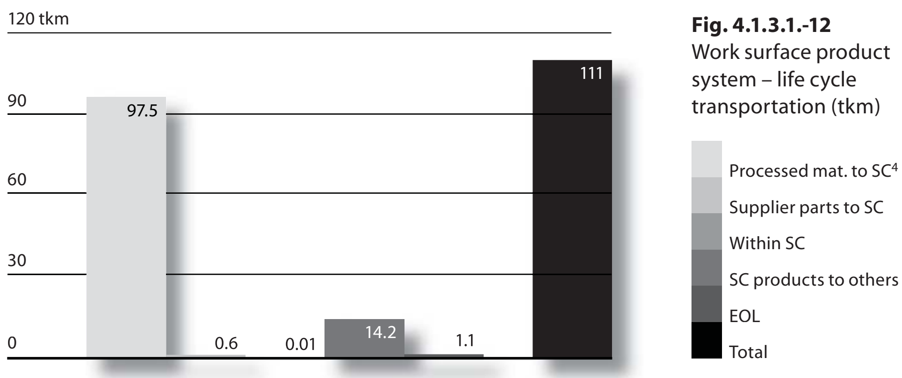


Fig. 4.1.3.1.-12
Work surface product system – life cycle transportation (tkm)

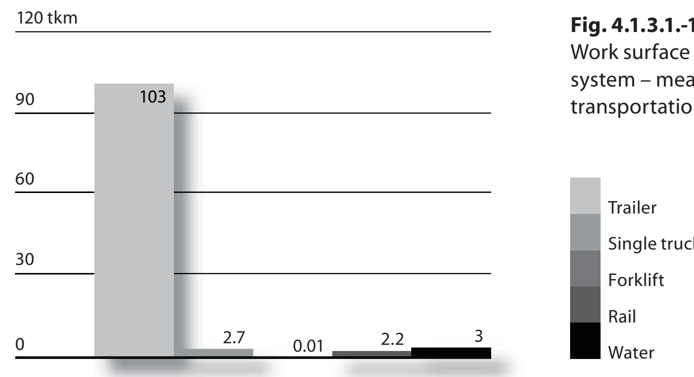


Fig. 4.1.3.1.-13
Work surface product system – means of transportation (tkm)

1 Meeting note; Steelcase Inc.; Grand Rapids, MI; August 27, 2003
2 SC = Steelcase; (r) = recycled; (l) = landfilled; (i) = incinerated
3 N/A = no information available
4 Meeting note; Phil Hester; Steelcase Inc.; Grand Rapids, MI; June 18, 2004
5 E-mail note; Denise Van Valkenburg; Steelcase Inc.; Grand Rapids, MI; June 21, 2004

Specific flows

In Table 4.1.3.1.-2 various material- and energy flows are viewed more specifically in order to make them understandable from an operations point of view. Environmental impacts for the greyed items were already accounted for previously as part of the five general life cycle impact categories 'energy resource consumption', 'global warming potential', 'acidification potential', 'criteria pollutants', and 'solid waste'. Besides these, Table 4.1.3.1.-2 introduces water consumption and overhead intensity as additional environmentally relevant measures.

Table 4.1.3.1.-2 Specific material- and energy flows associated with work surface product system

Flow	Amount	
Materials in product, total	37.90	kg
Manufacturing waste @ Steelcase	6.15	kg
Water, total	294.00	kg
Water @ Steelcase	6.10	kg
Overhead intensity @ Steelcase	20.50	m^2
Workspace lighting @ Steelcase	0.73	kWh
Individual fan operation @ Steelcase	0.28	kWh
Electricity, total	15.40	kWh
Electricity @ Steelcase	12.60	kWh
Natural gas, total	7.40	kg
Natural gas @ Steelcase	0.04	kg
Oils & lubricants @ Steelcase	0.01	kg

As Table 4.1.3.1.-2 shows, the manufacturing of the work surface product system requires 294 kg of fresh water (equals 184 gallons), of which 241 kg (82%) are related to steel production. 5.7 kg of fresh water (2%) per work surface product system are used at Steelcase facilities for general overhead. Compared to the lateral file- and panel product system, with 1520 kg and 1560 kg in fresh water consumption respectively, the work surface product system requires considerably less water. This is mainly due to the overall lower product system weight of the work surface, the product system's usage of less steel and in particular plastic materials, and the moderate fresh water requirements for particleboard manufacturing. The latter constitutes about 50% of the product system's total weight. With 20.5 m^2, the work surface product system has higher overhead requirements than the panel product system (14 m^2) and comes close to the lateral file product system (22.4 m^2). The low throughput rates for the particleboard laminating, -cutting, and -trimming processes are why the work surface product system has a relatively high overhead coverage.[1]

4.1.3.2. Work surface product system discussion

This Section looks at the environmental burdens related to the manufacturing of a work surface product system from a systems perspective. Table 4.1.3.2.-2 gives an overview of the LCA's main results reported in Section [4.1.3.1.].

Material production stage

The material production stage is the most dominant stage with respect to both the four life cycle stages as well as the full range of impact categories except for 'solid waste' (Table 4.1.3.2.-2). With regard to transportation, this study does not explicitly report transportation activities during raw material acquisition since those are already embedded in the material production processes and cannot be easily distinguished (see also Section [4.1.3.1.]). For the material production stage, laminate (3.8 kg) occurs to be among the leading contributors concerning the impact categories 'energy resource consumption', 'acidification potential', and 'criteria pollutants'. Also, the manufacturing of 1.9 kg aluminum (25% recycled content) shows major environmental impacts across the board and dominates the solid waste impact category. Other significant environmental impacts for the manufacturing stage are associated with the fabrication of steel (12.1 kg) and particleboard (19.1 kg). Regarding steel, environmental impacts are due mainly to the use of 1 kg of coal and 21 kg of water for every kg steel produced.[2] For particleboard most of the environmental impacts stem from the application of resin materials, the amount of board used (19.1 kg), as well as notable transportation activities related to particleboard delivery (79 tkm). For comparison purposes, Table 4.1.3.2.-1 shows various manufacturing materials along with their respective energy intensities.

Supplier manufacturing stage

The supplier stage is the third most influential of all four life cycle stages concerning the work surface product system (Table 4.1.3.2.-2). Here, the majority of environmental impacts (>94%) is related to aluminum casting followed by minor contributions from PVC extrusion (2-4%). In both cases, environmental burdens are chiefly related to energy consumption for heating purposes (natural gas and electricity), which is 41 MJ/kg for non-ferro casting and 6.4 MJ/kg for PVC extrusion.

Table 4.1.3.2.-1 Material comparisons based on energy resource consumption for production

Material	Energy res. cons.	
Steel, cold rolled coil (IISI)	24	MJ/kg
Steel, hot rolled coil (IISI)	21	MJ/kg
Steel, section, EAF route, 100% rec. (IISI)	10	MJ/kg
Copper (Idemat)	92	MJ/kg
Aluminum, primary (Idemat)	192	MJ/kg
Aluminum, 80% rec. (Idemat)	19	MJ/kg
PA 6.6 (Nylon, APME)	142	MJ/kg
PET bottle grade (APME)	79	MJ/kg
PVC (APME)	57	MJ/kg
Kraft paper (Franklin)	35	MJ/kg
Kraft unbleached, 100% rec. (Franklin)	17	MJ/kg
Particleboard (BEES)	12	MJ/kg
Wood, oak (Idemat)	10	MJ/kg
Wood, silver fir (Idemat)	2	MJ/kg

Steelcase manufacturing stage

Across all life cycle stages, the Steelcase stage causes the second largest environmental impact for the work surface product system. Except for solid waste, the majority of these impacts relates to 11.5 kWh in electricity consumed (Electricity_ConsumersEnergy) for each work surface product system manufactured. As Table 4.1.3.2.-2 demonstrates, most of the electricity usage is related to machinery, powder coating, welding, and compressed air. Compared to the product systems 'lateral file' and 'panel', the work surface product system generates a considerably higher amount of solid waste during the Steelcase manufacturing stage. That is, solid waste (9.1 kg) not only comes from electricity generation and powder coating over-spray but also includes 6.7 kg of laminate- and particleboard manufacturing waste. As the latter is incinerated, about 55 MJ (LHV) in energy can be recovered through electricity generation, which, does not make up for the amount of energy originally invested in producing the same amount of virgin material (see also impact category 'energy resource consumption' of this Section). With respect to overhead, the work surface product system covers 20.5 m^2, which is relative high and mainly related to floor space demands and low throughput rates for the particleboard operations.[3] Concerning transpor-

1 The allocation of overhead to manufacturing processes is described in greater detail in Sections [2.3.] and [3.2.2.]

2 IISI – International Iron and Steel Institute; data on Cold Rolled Coil, BF Route; August 2002

3 The allocation of overhead to manufacturing processes is described in greater detail in Sections [2.3.] and [3.2.2.]

Table 4.1.3.2.-2 LCA results for manufacturing a work surface product system reported for various impact categories and along all life cycle stages

Impact category		**Product life cycle stage** Material production	Supplier manufacturing	Steelcase manufacturing	End-of-life
Energy resource consumption (1520 MJ LHV)	% of system total	84%	5.5%	10%	0%
	% of stage total	- 23% laminate production - 23% particleboard production - 23% aluminum fabrication - 22% steel production	- 94% non-ferro cast work - 4% extrusion PVC	- 36% machinery - 24% powder coating - 20% welding - 13% compressed air	
Global warming potential (91 kg CO_2 eqv.)	% of system total	82%	6%	12%	0.6%
	% of stage total	- 41% steel production - 21% aluminum fabrication - 19% particleboard production - 11% laminate production	- 94% non-ferro cast work - 4% extrusion PVC	- 36% machinery - 24% powder coating - 20% welding - 13% compressed air	
Acidification potential (44 H^+ mol eqv.)	% of system total	84%	7%	9%	0.2%
	% of stage total	- 32% laminate production - 29% aluminum fabrication - 17% particleboard production - 9% steel production	- 93% non-ferro cast work - 5% extrusion PVC	- 34% machinery - 26% powder coating - 22% welding - 14% compressed air	
Criteria pollutants (0.0145 DALYs)	% of system total	85%	5.5%	9%	0.7%
	% of stage total	- 24% laminate production - 22% aluminum fabrication - 13% steel production - 11% particleboard production	- 95% non-ferro cast work - 4% extrusion PVC	- 37% machinery - 23% powder coating - 20% welding - 13% compressed air	
Solid waste (53 kg)	% of system total	29%	1%	15%	55%
	% of stage total	- 77% aluminum fabrication - 12% steel production - 8% laminate production	- 98% non-ferro cast work - 2% extrusion PVC	- 74% particleboard & laminate - 7% machinery - 6% powder coating - 5% welding	
Transportation (111 tkm)	% of system total	86 %	0.5%	13%	1%
Water consumption (294 kg)	% of system total	94%	4%	2%	0%

tation, the Steelcase stage accounts for 13% (14.2 tkm) of the total system transportation activities of 111 tkm. Overall, the latter makes up for 7% of the system's total energy resource consumption, which is twice as high as for the lateral file- and panel product systems.

End-of-life stage

Environmental burdens related to the EOL stage are negligible concerning most of the impact categories except for 'solid waste' (Table 4.1.3.2.-2). Due to the retirement of the entire product system during this stage, EOL solid waste accounts for 55% of total solid waste generated along the entire life cycle of a work surface product system. As described in Section [2.3.], U.S. EPA data on waste management for durable goods (which includes furniture products) as well as packaging materials report recycling rates of 28% for steel, 0% for aluminum, 60% for other non-ferro metals, and 5.5% for plastics.[1] Since, as of yet, Steelcase does not have a deliberate end-of-life management system in place, Steelcase products are assumed to enter the standard U.S. waste management process at the end of their useful lives.

As a consequence, 3.7 kg in ferro metals and 0.1 kg in plastics are ultimately recycled out of a total of 12.3 kg and 2.1 kg respectively (Fig. 4.1.3.2.-1).[2] The remainders in ferro metals (8.6 kg) and plastic materials (2 kg) are either landfilled, incinerated, or fed into unknown waste management processes.

At this point, it becomes apparent that the terms 'recycled content', 'recycability', and 'recycled materials' should not be confused and that a clear distinction has to be made between them in order to accurately represent product related life-cycle facts. For example, 'recycled content' for the original product system does not necessarily imply that the related materials can and will be properly recycled at the product's end of life. Also, 'recycability' does not reveal anything about whether the original product system contains recycled materials or whether material recycling takes place at the product system's end of life. Similarly, 'recycled materials' during the end-of-life stage of a product system do not automatically infer that recycled materials were a constituent of the original product system. As demonstrated with all three product systems, a combination of back-end and front-end strategies is required in order to sufficiently close material loops. So far, with regard to the work surface product system 12% of manufacturing- and EOL scrap/waste combined is recycled, whereas 88% are lost.

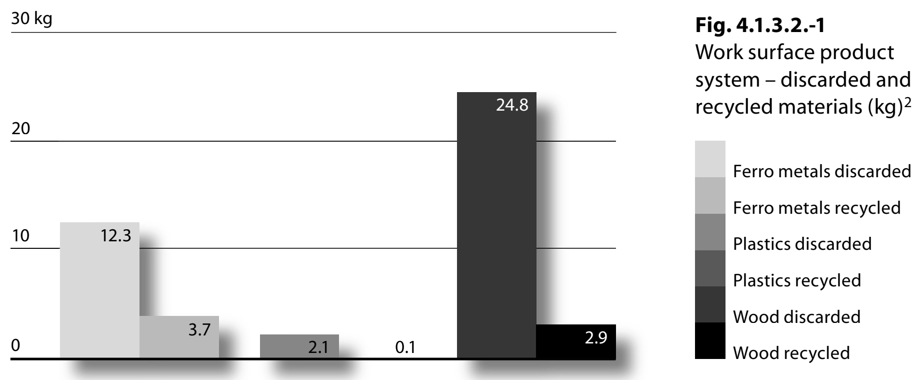


Fig. 4.1.3.2.-1
Work surface product system – discarded and recycled materials (kg)[2]

1 U.S. Environmental Protection Agency; Municipal Solid Waste in the United States; Washington D.C., USA; October 2003
2 Numbers include flows and treatment of manufacturing scrap/waste

4.1.3.3. Work surface product system conclusions

As reported and discussed in Sections [4.1.3.1.] and [4.1.3.2.], environmental impacts are generated across the entire work surface product system life cycle. The main drivers, however, are part of the material production stage. Aluminum- (5% of total product weight), laminate- (10% of total product weight), steel- (31% of total product weight), and particleboard fabrication (49% of total product weight) are responsible for most of the environmental burdens. For solid waste generation alone, aluminum is the dominant factor throughout the material production stage (77% of stage total). Laminate production causes disproportionately high environmental burdens for the impact categories 'energy resource consumption', 'acidification potential', and 'criteria pollutants'. This is despite the fact that laminate comprises no more than 10% of the product system's total weight. The usage of kraft paper and resins, and the need for process heat in composite backing are major reasons for this. Concerning particleboard, most environmental burdens are related directly to material intensity (19 kg), resin application, and long-distance trucking (3 tkm per kg of particleboard). Shipping particleboard from Oregon to Michigan highly affects trucking. 2.5% (1 kg) of all work surface product system materials are plastics, including 0.5 kg of PVC. Virgin PVC shows a comparatively low production energy (57 MJ/kg), however, it has to be considered critical under human toxicity aspects, particularly due to frequently applied plasticizer substances (Table 4.1.3.2.-1).[1]

As most of the work surface product system is manufactured at Steelcase facilities, environmental impacts for the supplier stage are relatively low and mainly comprise burdens from aluminum casting.

Regarding the Steelcase stage, most of the environmental impacts, except for solid waste, come from electricity consumption (99%) for machinery, powder coating, welding, and compressed air. Unlike the lateral file- and panel product systems, electric heaters for laminating purposes make machinery the top electricity consumer regarding the work surface Steelcase stage. In terms of solid waste, 15% of the product system total of 53 kg is generated here, mainly because of considerable manufacturing waste from particleboard/laminate cutting and powder coating over-spray. Compared to the lateral file product system, fresh water consumption during this stage is relatively low for the work surface product system as only few pieces of manufacturing equipment need to be cooled (automatic presses, welders).

The end-of-life stage leads to considerable environmental impacts only with respect to solid waste. Fifty-five % of the total product system solid waste accrues during this stage. This is mainly due to the fact that the whole product system is disposed and that the overall recycling rates reported for the U.S. municipal waste management system are fairly low.

Based on the study results for the work surface product system the following leverage points for environmental improvement can be identified:

- Overall product weight and amount of materials, especially particleboard and steel used in product system
- Recycled content of aluminum and steel used in product system
- Utilization of conventional laminate- and particle board materials
- Application of PVC plastics
- Electricity consumption and sourcing at Steelcase facilities
- Material- and energy efficiency of powder coating processes
- Material efficiency of work surface manufacturing/ cutting (manufacturing scrap/waste)
- Supplier compliance with (Steelcase and other) environmental standards
- Material recovery at product end-of-life

1 The most common PVC plasticizers are phtalates, of which DEHP, DIDP, and DINP are the most common phtalates. This issue was not further elaborated in this study

4.2. Comparative analysis and discussion (based on product system weight)

Tables 4.2.-1 through 4.2.-5 show environmental impacts reported and discussed in Section [4.1.] as normalized values based on product system weights for all three product systems. Although the lateral file-, panel-, and work surface product systems cannot be compared directly in terms of a common functional unit, this discussion allows for identifying product system specific impacts more clearly by juxtaposing the results across all impact categories and product systems relative to the individual product system weights (in the following called 'impact/kg').

In Fig. 4.2.-1, the panel product system renders the highest energy resource consumption/kg for the material production stage, which directly relates to its high aluminum content (9.3 kg). Although the work surface product system utilizes some aluminum too, the amounts used there are much lower (1.9 kg). Further implications are caused by the fact that this study does not account for renewable energy resources. As such, production energy related to particleboard manufacturing through wood waste incineration (work surface product system) does not impact model results. Nevertheless, energy resource intensity for the work surface product system is still higher than for the lateral file product system. This is mainly due to high energy demands for aluminum-, PVC-, and laminate fabrication (see Table 4.1.3.2.-1).

Aluminum casting also makes the panel product system the major consumer of energy resources/kg for the supplier stage.

With respect to the Steelcase stage, it is the lateral file product system that shows the greatest energy resource consumption/kg impacts. Energy intensive welding- and powder coating processes, as well as the use of heavy equipment (automatic presses), are the most influential factors here.

Global warming potential/kg shows a distribution similar to the one for energy resource consumption (Fig. 4.2.-2). However, the lateral file product system renders a higher global warming potential than what would be expected based on the consumption of energy resources. This relates to the fact that aluminum production for the panel- and work surface product system uses hydroelectric power, which causes relatively low greenhouse-gas emissions. However, some of the energy resources for the panel- and work surface product systems end up as feedstock energy and thus, are not combusted during the material production process (plastics, fabrics, laminates, etc.).

For the supplier stage, again, aluminum casting makes the panel product system the most potent product system also in terms of greenhouse-gas emissions/kg.

Electricity consumption for powder coating-, welding-, and blanking/stamping equipment makes the lateral file product system the most GHG-intensive system for the Steelcase stage (greenhouse-gas emissions/kg).

Fig. 4.2.-3 indicates acidification potentials/kg for all three product systems. For the material production stage, the lateral file product system renders a considerably lower acidification potential than the other two product systems. Overall, this is due to comparatively low acidification potentials for steel manufacturing and conversely, high acidification potentials for the fabrication of aluminum, cardboard, and plastic materials (including resins). Almost none of the latter two are applied in the lateral file product system.

For the supplier stage, aluminum casting, and to a smaller degree zinc coating for the panel product system, constitute most of the acidification potential/kg impacts.

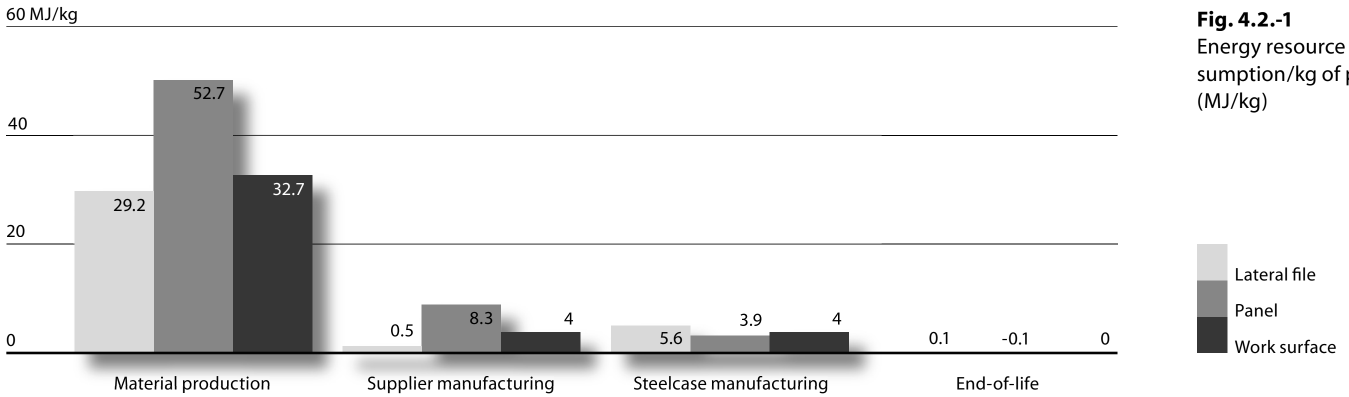


Fig. 4.2.-1
Energy resource consumption/kg of product (MJ/kg)

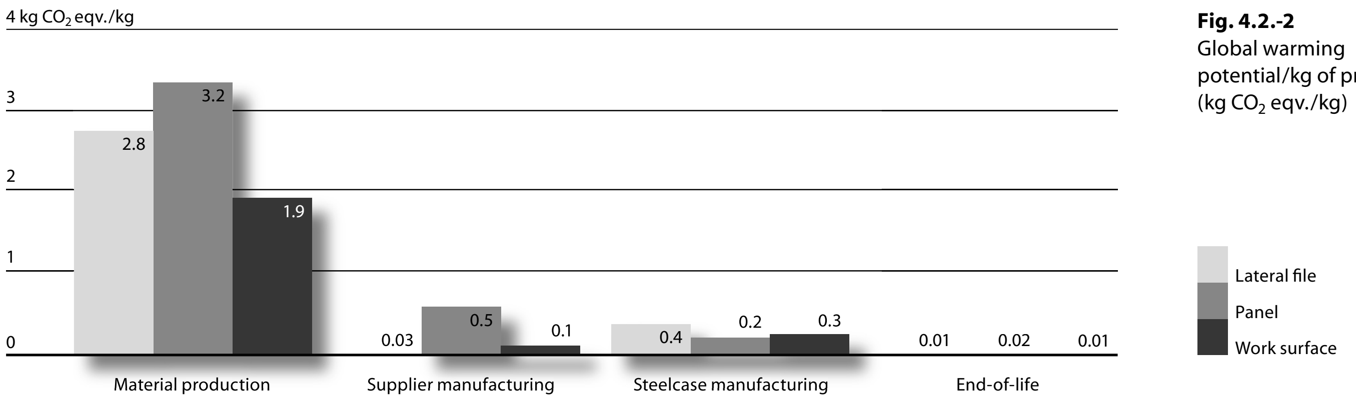


Fig. 4.2.-2
Global warming potential/kg of product (kg CO_2 eqv./kg)

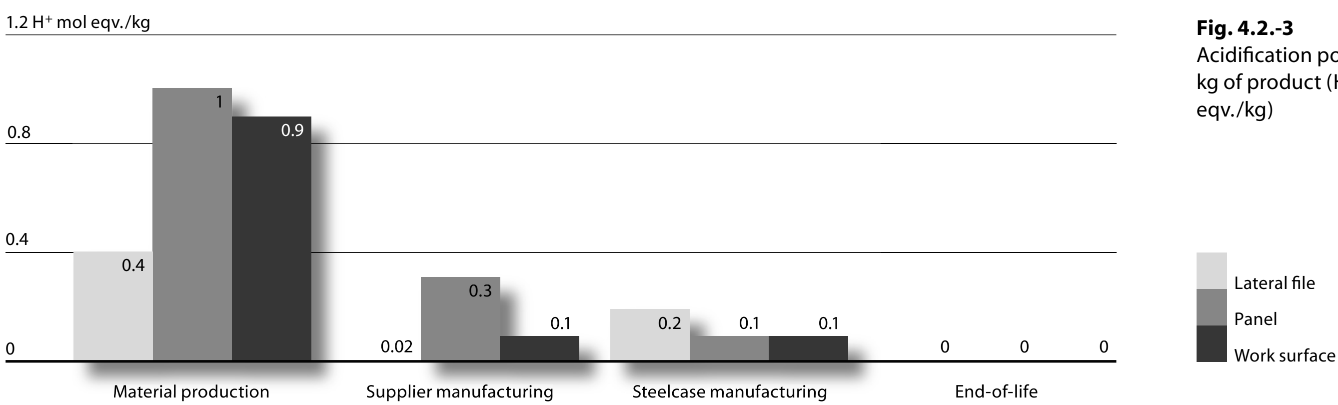


Fig. 4.2.-3
Acidification potential/kg of product (H^+ mol eqv./kg)

Across all product systems and with respect to acidification potential/kg, the Steelcase stage, once more, is dominated by emissions related to the generation of electricity used in the manufacturing of a lateral file product system (powder coating, welding, automatic presses).

As illustrated in Fig. 4.2.-4, criteria pollutants/kg of product weight show a different distribution for the material production stage than seen with Figures 4.2.-1 through 4.2.-3. Here, the work surface product system surmounts both the lateral file- and panel product systems in terms of criteria pollutants/kg. This is due to disproportionately high emissions of criteria pollutants during particleboard manufacturing and transportation. Compared to the lateral file product system, aluminum production causes significantly higher emissions for both the panel- and the work surface product system. A major contributor to this is electricity generation from coal.

Concerning the supplier stage, again, aluminum casting related to the panel product system triggers the highest environmental impacts also with respect to criteria pollutants/kg.

As seen before, electricity consumption for the manufacturing of a lateral file product system at Steelcase facilities is the major cause also for the emission of criteria pollutants/kg during the Steelcase stage.

As demonstrated in Fig. 4.2.-5, the work surface product system leads the material production stage in terms of solid waste generation/kg, followed by the panel- and lateral file product systems. This is due chiefly to the special alloy used in the C-leg aluminum bases, which contains 4% copper. In general, copper manufacturing generates substantial amounts of solid waste (134 kg of solid waste/kg copper[1]).

Across all product systems aluminum casting for the panel product system dominates solid waste generation regarding the supplier stage. In this case, however, solid waste is related to a lesser degree to manufacturing waste from casting but the provision of casting related energy carriers (electricity and natural gas).

Unlike the impact categories/kg addressed so far, the work surface product system generates most of the solid waste/kg during the Steelcase stage due to manufacturing waste from particleboard cutting (including laminates).

Major environmental impacts for the end-of-life stage only occur with respect to solid waste/kg. Here, the work surface product system demonstrates the highest releases, closely followed by the panel- and lateral file product systems. This is largely related to the specifics of the U.S. municipal waste management system and the handling of durable goods within it. As such, only a small fraction of the disposed particleboard (15%) and none of the aluminum gets recycled but is ultimately landfilled (56%) or incinerated (15%).[2]

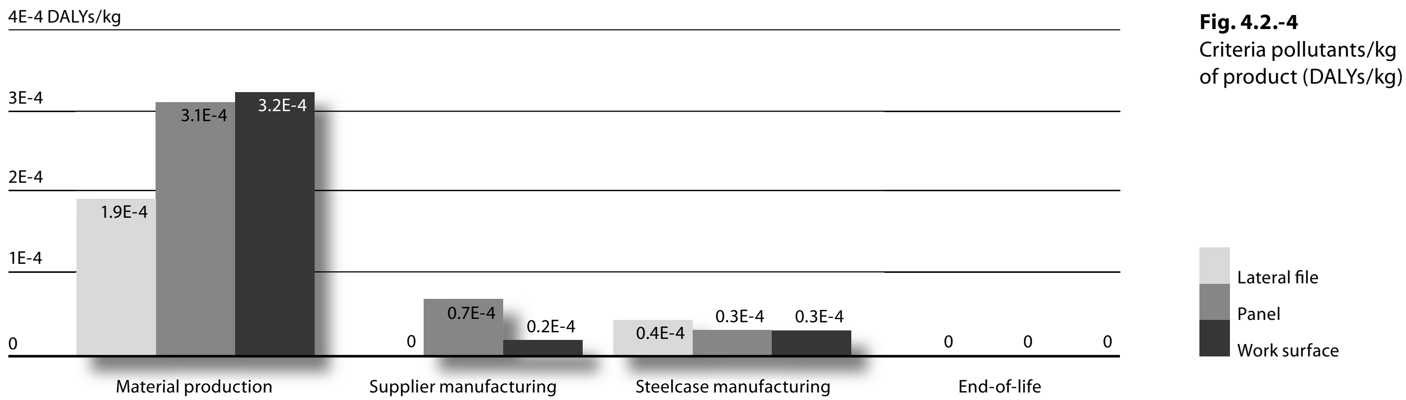


Fig. 4.2.-4
Criteria pollutants/kg of product (DALYs/kg)

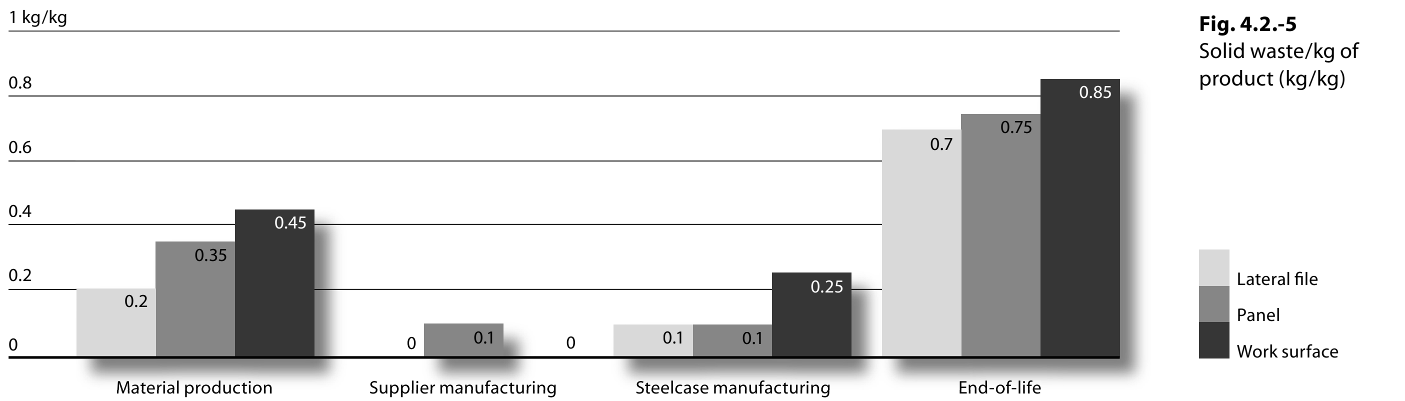


Fig. 4.2.-5
Solid waste/kg of product (kg/kg)

1 According to SimaPro Data Archive; Idemat data on "Copper I"; PRé Consultants; Amersfoort; The Netherlands; 1994
2 A detailed description of the EOL waste management scenario applied in this study can be found in Section [2.3.]

5. Conclusions and recommendations

This project focused on life cycle assessment (LCA) of three office furniture product systems currently produced and marketed by Steelcase Inc. in Grand Rapids, Michigan. The product systems were a lateral file product, a panel product – as part of a broader modular architectural system for office space structuring – , and a work surface product (office desk). The study findings are intended to provide useful insights to the Steelcase community – and in particular to those who are involved with environmental performance, product development, marketing, and corporate strategy – about environmental implications of three general types of Steelcase office furniture. As the first in-depth LCA conducted at Steelcase, this study establishes a benchmark for future steps and highlights opportunities regarding environmental improvements across various Steelcase business units. Particular interest was put on less obvious effects as well as counter-intuitive insights.

5.1. Conclusions

This section compiles insights revealed and reported for each product system in Chapter [4.]. Insights are derived from the results based on primary data collected at Steelcase facilities from either internal operational data repositories (Workmanager, SAP-R3, etc.), or original on-site research (interviews and observations), as well as secondary data readily available from LCA databases (specific information on data sources can be found in Chapter [3.2.]). These data were entered into comprehensive life cycle models in order to quantify environmental burdens along five major impact categories (energy resource consumption, global warming potential, acidification potential, criteria pollutants, and solid waste (excluding recyclables)). From modeling results, environmental impacts were assessed based on the TRACI scheme.[1]

Material production stage shows highest impacts

Study results show that the majority of environmental impacts, except for solid waste, occur during the material production stage (raw material acquisition and -processing). Product system mass – and thus the usage of considerable amounts of material – , the application of certain substances, and low rates of recycled content are the greatest determinants of environmental impact. Aluminum and plastic materials make up for a substantial share in energy resource consumption and acidification potential. Aluminum production at low recycling rates also generates substantial amounts of solid waste. Most of the aluminum is applied in the panel- and work surface product systems. Plastic materials of different kinds are mainly incorporated in the panel product system. Particleboard- and laminate materials in the work surface product system, however, should also be considered as plastics due to high contents in resin materials. Regarding the work surface product system, laminate production leads to environmental impacts across all impact categories, except for solid waste. Particleboard shows high impacts in terms of criteria pollutants due to both manufacturing procedure and transportation needs. Other materials of concern are cardboard and copper. A disproportionate amount of cardboard is used for packaging purposes concerning the panel product system. The panel product system consists of various individual parts, which are packaged and shipped to customers separately. This leads to considerable environmental burdens for all impact categories except 'energy resource consumption'. Copper is applied in welding tips and electrical equipment for the panel product system. Although low in actual amounts applied (0.04% of panel product system total weight), environmental impacts from copper production with regard to acidification potential, criteria pollutants, and solid waste in particular are comparatively high (1.2% - 4%).

Material recovery at product end-of-life is a critical factor in solid waste generation

Most solid waste across all product systems occurs during the end-of-life stage when product systems are disposed as a whole. Due to lack of end-of-life product stewardship, Steelcase products, once retired, enter the regular U.S. municipal waste management system. According to reported practices, only 28% of steel materials are recycled – and much lower rates are shown for many other common materials. As a consequence, recycling of manufacturing waste, although laudable, only recovers small amounts of production waste, whereas the majority of post consumer waste ends up in landfills.

Manufacturing waste can be significant

Study results indicate that the work surface product system generates manufacturing waste as high as 16% of the total amount of materials used. Most of it comprises particleboard- and laminate residues from cutting processes. Across all product systems, powder coating efficiencies of less than 60% causes notable amounts of manufacturing waste due to over-spray (between 0.5% and 1% of total product system material weight).

Steel performs comparatively well

Second only to certain wood materials and with the exceptions of global warming potential and water consumption, steel performs comparatively well with respect to all other environmental impact categories. Global warming potential is mainly due to blast-furnace processes harnessed in manufacturing the kinds of steel used in Steelcase product systems (hot- and cold rolled coil). Design strategies to reduce the amount of steel used would enhance environmental performance.

Electricity consumption at Steelcase facilities causes significant burdens

The vast majority of environmental impacts during Steelcase manufacturing stems from electricity usage. Contributions to the system total, depending on the product system and impact category, range from 4% to 29%. Most electricity across all product systems is consumed for powder coating, machinery, welding, and compressed air.

Facility location can have noticeable effects on energy consumption

During this study two different Steelcase manufacturing locations, Grand Rapids, Michigan, and Athens, Alabama, were evaluated. As study results show, higher ambient temperature- as well as humidity levels at the Athens facilities cause utilization of individual workplace fans to be twice as high than for the Grand Rapids facilities (4% vs. 2% of Steelcase stage total electricity consumption). However, site location- and design decisions have to be based on a broader facility study comparing various material- and energy flows for different Steelcase locations.

Manufacturing processes differ highly in environmental impacts

Various manufacturing processes are applied during the production of either product system under consider-

1 TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

ation. Identifying the most detrimental ones in terms of environmental impacts can inform the product development process about applying and developing new design strategies. As the results point out, aluminum casting, electroplating- and galvanic coating processes (nickel, chrome, zinc) demonstrate high energy resource consumption as well as global warming-, and acidification potential. The latter is either related to the actual chemical processes involved or to fossil fuels ultimately combusted for energy generation. Concerning steel handling, roller-presses are more energy efficient than mechanical presses, which, in turn, are less energy intensive than hydraulic presses.

Transportation burden is important

Transportation activities for all product systems consume between 2% (lateral file) and 7% (work surface) of total system energy resources. Transportation of raw materials and shipping of final products to customers are the main drivers. By far, the most transportation is done using diesel trailers, which contribute substantially to criteria pollutants.

5.2. Recommendations

In general, recommendations follow from the insights presented in Section [5.1.]. Due to the nature of the life cycle assessment applied here, recommendations are solely focused on environmental improvements concerning the product systems investigated. In this study, further relevant aspects, such as costing, operations, and product quality, were not evaluated. This must happen subsequently, as concepts, strategies and ideas are developed which address recommendations in fresh ways and from new perspectives.

Reduce material intensity

As the majority of impacts relate to raw material provision processes, material intensity, wherever feasible from a functional perspective, should be reduced for all product systems. Revised design-, construction-, and manufacturing processes, as well as environmentally conscious material sourcing strategies should therefore be applied. Many of those opportunities lie within Steelcase's core business and operations and can thus be tackled directly. Suppliers should be evaluated and chosen accordingly. Light-weight design strategies should be harnessed across the board. In many instances, employing recycled materials – a strategy, which has been increasingly adopted during recent product development at Steelcase – can reduce raw material production impacts. Manufacturing waste not only affects solid waste but also increases material and transportation intensity of product systems. In this study, this is true in particular for the work surface product system.

Provide for end-of-life material recovery

In order to reduce environmental burdens, Steelcase must look beyond their own operations. From a life cycle perspective, the majority of materials embedded in Steelcase product systems inevitably gets lost in the U.S. municipal waste management system. For "recycled content" to be a feasible concept, material recovery at the post consumer level is crucial. As such, Steelcase ought to facilitate those processes either directly or indirectly by setting up proprietary systems (product take-back) or by cooperating with third parties. For the latter, material could be retrieved from non-Steelcase related waste streams, for which Steelcase is then given credit for regarding their own material consumption.

Identify material- and process substitutes

Besides reducing material intensities, substitutes can be explored for environmentally harmful materials, especially when these can be easily replaced. As such, copper, unrecycled aluminum, regular laminates, and certain plastics[1] should be eliminated from Steelcase product systems. Likewise, notorious manufacturing practices such as galvanic-, and electro-plating processes should be designed out of Steelcase products. In general, those activities show high energy resource consumption, acidification potential, and toxicity factors (human- and eco-toxicity).[2] Overall, positive lists of environmentally sound materials and -processes relevant to Steelcase should be established in order to facilitate the future conception, -design, and -development of Steelcase product systems.

Optimize logistics

Environmental burdens related to logistics depend on packaging- and transportation needs. Packaging intensity is highest for the panel product system and mainly comprises cardboard and LDPE film. Both materials show high energy resource demands and thus acidification potential, which indicates the need for material reduction and/or substitution. Steelcase packaging strategies should be revised in terms of possible take-back and/or reusable systems as well as the utilization of less processed- and renewable materials (fabrics, paper-pulp molds, air-cushions, starch-flocks, etc.). Easy compostability can supplement these strategies. Transportation related impacts chiefly depend on weight, shipping distance, means/technology of transportation, and capacity utilization. From a material sourcing perspective, Steelcase should opt for supply channels with less transportation related impacts (which does not necessarily imply the shortest shipping distance). With respect to commodities, this is not an easy assignment and may require long-term commitments with clusters of low-impact suppliers. Weight reduction of Steelcase products, will have positive impacts on transportation effects, as will the reevaluation of transportation modes. Product system delivery from Steelcase to customers is done chiefly with diesel trailers operated by Steelcase itself. This provides a good and direct opportunity for reassessing the logistic system from a strategic point of view. As such, deliberations range from delivery hubs to which Steelcase products are shipped by more environmentally sound means of mass-cargo transportation to the application of forward-looking road technologies (hybrid vehicles, alternative fuels, etc.).

Reduce burdens from steelcase electricity consumption

Despite past measures in electricity conservation, such as energy efficient lighting fixtures and leak detection in compressed air systems, electricity consumption at Steelcase facilities causes substantial environmental burdens. For improved performance, electricity use must be reduced; electricity must be substituted by less burdensome energy carriers where useful; and remaining electricity needs must be increasingly met by renewable sources. This effects various aspects of Steelcase business especially related to manufacturing and facility operation/overhead. As study results show with respect to workplace ventilation, even marginal issues like siting of Steelcase facilities can have noticeable effects on subsequent electricity/energy consumption and thus, must be addressed holistically. Another leverage point for improvements regarding electricity usage are powder coating lines, which harness electricity for heating purposes. Also, welding equipment and heavy machinery (like automatic presses), which both require water cooling, should be applied resourcefully and replaced by more efficient technologies over time. Ultimately, compressed air as a power providing medium ought to be reevaluated, as thermodynamic constraints cause high generation losses and hence low system efficiencies.

1 At this point no specific recommendations could be made. Plastic materials vary considerably with respect to environmental performance across different impact categories as well as other issues such as recyclability. In general, energy resource consumption for virgin plastics is relatively high and recycled matter should be preferred whenever possible. In any case, further research is needed to give more specific advice
2 According to SimaPro Data Archive; data on "Zinc coating S" (ETH-ESU), "Chromium electroplating I" (Idemat), and "Nickel electroplating I" (Idemat); PRé Consultants; Amersfoort; The Netherlands; 1994

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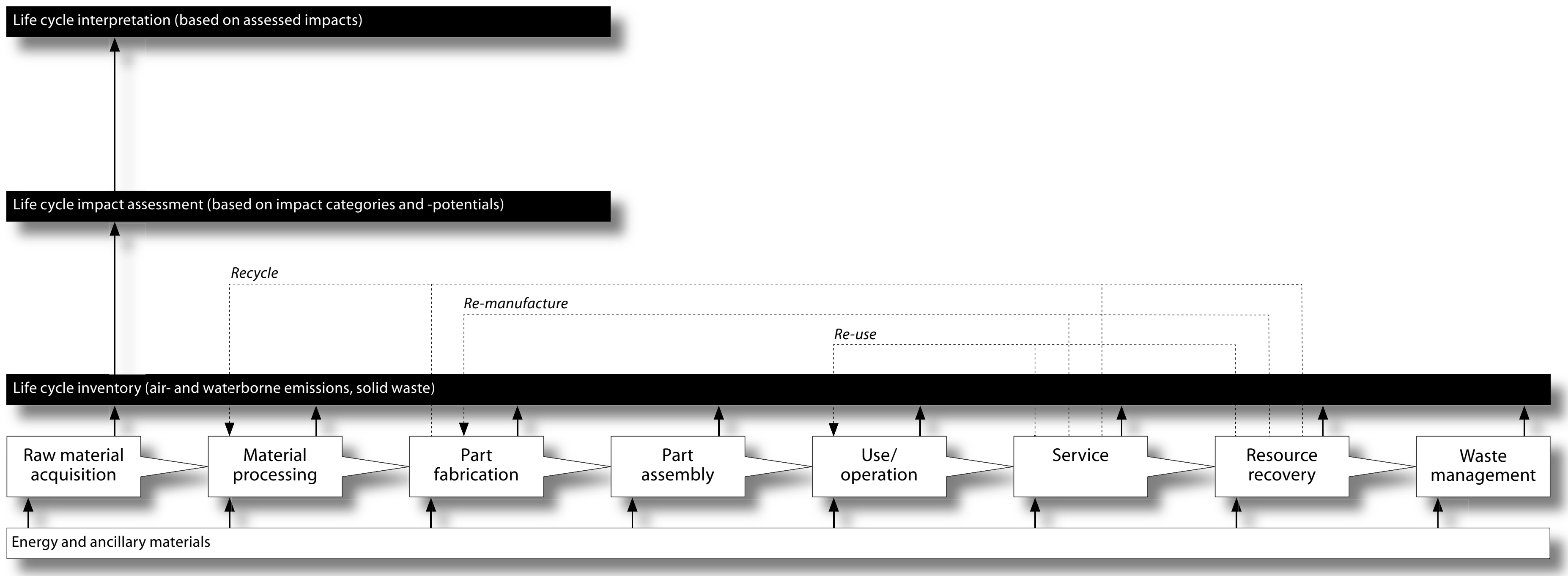
Appendix A

Generic life cycle assessment process



Appendix B

Steelcase-specific processes applied in this study

Process[1]	Allocation unit[2]
Manufacturing/operations	
Air make-up unit operation, Athens	hr
Air make-up unit operation, GR	hr
Compressed air, Athens	cf
Compressed air, GR	cf
Cooling water, Athens	kg
Cooling water, GR	kg
Electric handtool, Athens	hr
Electric handtool, GR	hr
Individual fan operation, Athens	hr
Individual fan operation, GR	hr
Lighting fixture, 1500 watts, Athens	hr
Lighting fixture, 400 watts, Athens	hr
Lighting fixture, 480 watts, GR	hr
Overhead, Athens	sqf
Overhead, GR	sqf
Powder coating, Athens, 40% usage rate	sqf
Powder coating, GR, 40% usage rate	sqf
Space lighting, Athens	p
Space lighting, GR	p
Welding, MIG, Athens	inch
Welding, MIG, GR	inch
Welding, projection, Athens	p
Welding, projection, GR	p
Welding, spot (foot stamper), Athens	p
Welding, spot (foot stamper), GR	p
Maintenance	
Sec. flows BAP, Athens	hr
Sec. flows BAP, GR	hr
Sec. flows BMP, GR	hr
Sec. flows DRILL, GR	hr
Sec. flows MHP, Athens	hr
Sec. flows MHP, GR	hr
Sec. flows MMP, Athens	hr
Sec. flows MMP, GR	hr
Sec. flows ROLLFROM, Athens	hr
Sec. flows ROLLFROM, GR	hr
Sec. flows SMP, Athens	hr
Sec. flows SMP, GR	hr
Energy	
Electricity Consumers-Energy-Co.	MWh
Electricity Tennessee-Valley-Authority	MWh
Transportation	
Forklift operation, Athens	tkm
Forklift operation, GR	tkm
Manufacturing waste	
MW steel scrap, CRC, Athens	kg
MW steel scrap, CRC, GR	kg
MW steel scrap, HRC, Athens	kg
MW steel scrap, HRC, GR	kg
MW steel scrap, WP, Athens	kg
MW steel scrap, WP, GR	kg
MW PE fabric, to landfill, Athens	kg
MW PE fabric, to recycling, Athens	kg
MW PE powder to landfill, Athens	kg
MW PE powder to landfill, GR	kg
MW PVC, to landfill, GR	kg
MW particleb./-dust, to energy recov., GR	kg
MW particleboard/-dust, to LFG recov., GR	kg
MW laminate, to landfill, GR	kg

1 BAP = big automatic press
BMP = big mechanical press
MHP = medium hydraulic press
MMP = medium mechanical press
SMP = small mechanical press
MW = manufacturing waste
CRC = cold-rolled coil
HRC = hot-rolled coil
WP = welded pipes
LFG = landfill gas

2 cf = cubic foot
sqf = square foot
p = piece
tkm = ton (metric) kilometer

Appendix C

Life cycle impact categories and potentials as defined in TRACI[1] environmental impact assessment framework

Impact cat.	Active substance		Impact pot.
Global warming			***kg CO_2 eqv.***
Air	CO_2	kg	1
Air	CO_2 (fossil)	kg	1
Air	CO_2 (non-fossil)	kg	0
Air	methane	kg	23
Air	N_2O	kg	296
Energy resource consumption (based on Ecoindicator 95)			***MJ-LHV***
Raw	barrage water	kg	0.01
Raw	biomass (feedstock)	MJ	1
Raw	coal	kg	29.3
Raw	coal (feedstock) FAL	kg	26.4
Raw	coal ETH	kg	18
Raw	coal FAL	kg	26.4
Raw	crude oil	kg	41
Raw	crude oil (feedstock)	kg	41
Raw	crude oil (feedstock) FAL	kg	42
Raw	crude oil ETH	kg	42.6
Raw	crude oil FAL	kg	42
Raw	crude oil IDEMAT	kg	42.7
Raw	energy (undef.)	MJ	1
Raw	energy from coal	MJ	1
Raw	energy from hydro power	MJ	1
Raw	energy from lignite	MJ	1
Raw	energy from natural gas	MJ	1
Raw	energy from oil	MJ	1
Raw	energy from uranium	MJ	1
Raw	energy from wood	MJ	0
Raw	energy recovered	MJ	1
Raw	gas from oil production	m^3	40.9
Raw	lignite ETH	kg	8
Raw	lignite	kg	10
Raw	methane (kg)	kg	35.9
Raw	natural gas	kg	30.3
Raw	nat. gas (feedstock)	m^3	35
Raw	nat. gas (feedstock) FAL	kg	46.8
Raw	natural gas (vol)	m^3	36.6
Raw	natural gas ETH	m^3	35
Raw	natural gas FAL	kg	46.8
Raw	petroleum gas ETH	m^3	35
Raw	pot. energy hydropower	MJ	1
Raw	steam from waste incin.	MJ	1
Raw	unspecified energy	MJ	1
Raw	uranium (in ore)	kg	451000
Raw	uranium (ore)	kg	1110
Raw	uranium FAL	kg	2291
Raw	wood	kg	0
Raw	wood (feedstock)	kg	0
Raw	wood & wood wastes FAL	kg	0
Raw	wood/wood wastes FAL	kg	0
Acidification			***kg H^+ eqv.***
Air	ammonia	kg	95.4852
Air	HCl	kg	44.6952
Air	HF	kg	81.264
Air	NO_x	kg	40.04
Air	NO_x (as NO_2)	kg	40.04
Air	SO_2	kg	50.79
Air	SOx (as SO_2)	kg	50.79
Air	NO	kg	61.2612
Air	NO_2	kg	40.04
Air	SO_x	kg	50.79
Criteria pollutants/ human health			***DALYs***
Air	NO_2	kg	0.002212641
Air	NO_x	kg	0.002212641
Air	NO_x (as NO_2)	kg	0.002212641
Air	particulates (PM_{10})	kg	0.083448172
Air	particulates ($PM_{2.5}$)	kg	0.139080287
Air	particulates (SPM)	kg	0.045896495
Air	SO_2	kg	0.013908029
Air	SO_x	kg	0.013908029
Air	SO_x (as SO_2)	kg	0.013908029
Eutrophication			***kg N eqv.***
Air	ammonia	kg	0.1186
Water	BOD	kg	0.05
Water	COD	kg	0.05
Water	COD (sea)	kg	0.05
Water	NH_4^+	kg	0.7793
Water	NH_4^+ (sea)	kg	0.7793
Water	nitrate	kg	0.2367
Water	nitrate (sea)	kg	0.2367
Air	NO	kg	0.06858
Air	NO_2	kg	0.04429
Air	NO_x	kg	0.04429
Air	NO_x (as NO)	kg	0.04429
Water	N-tot	kg	0.9864
Air	P	kg	1.12
Water	P	kg	7.29
Water	phosphate	kg	2.38
Water	phosphate (sea)	kg	2.38
Water	P-tot	kg	7.29
Air	P-tot	kg	1.12

Solid waste			
Solid	aluminium scrap	kg	0
Solid	aluminium waste	kg	0
Solid	asbestos	kg	1
Solid	ash	kg	1
Solid	asphalt waste	kg	1
Solid	bilge oil	kg	1
Solid	bilge oil waste	kg	1
Solid	bitumen waste	kg	1
Solid	building waste	kg	1
Solid	bulk waste	kg	1
Solid	calciumfluoride	kg	1
Solid	cardboard	kg	0
Solid	carton waste	kg	0
Solid	catalyst waste	kg	1
Solid	chemical waste	kg	1
Solid	chemical waste (inert)	kg	1
Solid	chemical waste (regulated)	kg	1
Solid	coal ash	kg	1
Solid	coal tailings	kg	1
Solid	construction waste	kg	1
Solid	copper scrap	kg	0
Solid	copper waste	kg	0
Solid	drilling waste	kg	1
Solid	dross	kg	1
Solid	dross for recycling	kg	1
Solid	dust - not specified	kg	1
Solid	dust to landfill	kg	1
Solid	dust, break-out	kg	1
Solid	dust, particleboard	kg	1
Solid	electronic waste	kg	1
Solid	electrostatic filter dust	kg	1
Solid	glass	kg	0
Solid	glass waste	kg	0
Solid	high active nuclear waste	kg	1
Solid	final waste (inert)	m^3	1
Solid	limestone waste	kg	1
Solid	fly ash	kg	1
Solid	metal scrap	kg	0
Solid	mineral waste	kg	1
Solid	mineral waste (mining)	kg	1
Solid	mineral wool waste	kg	1
Solid	mixed plastics	kg	1
Solid	incinerator waste	kg	1
Solid	industrial waste	kg	1
Solid	inorganic general	kg	1
Solid	oil	kg	1
Solid	oil separator sludge	kg	1
Solid	other waste	kg	1
Solid	low, med. act. nucl. waste	kg	1
Solid	toxic waste	m^3	1
Solid	packaging waste	kg	1
Solid	paint waste	kg	1
Solid	paper/board packaging	kg	1
Solid	PE	kg	0
Solid	PE waste	kg	0
Solid	plastic production waste	kg	0
Solid	plastics packaging	kg	0
Solid	plastics waste	kg	0
Solid	printed circuitboards	kg	1
Solid	process waste	kg	1
Solid	prod. waste unspecified	kg	1
Solid	produc. waste (not inert)	kg	1
Solid	PS waste	kg	0
Solid	PV cell waste	kg	1
Solid	PV panel waste	kg	1
Solid	PV production waste	kg	1
Solid	PV/EVA cell waste	kg	1
Solid	PVC	kg	0
Solid	PVC waste	kg	0
Solid	radioactive waste (kg)	kg	1
Solid	refinery sludge	kg	1
Solid	rejects	kg	1
Solid	residues	kg	1
Solid	slag	kg	1
Solid	slags/ash	kg	1
Solid	sludge	kg	1
Solid	sludge ion exchanger	kg	1
Solid	solid waste	kg	1
Solid	soot	kg	1
Solid	steel packaging	kg	0
Solid	steel scrap	kg	0
Solid	steel waste	kg	0
Solid	stones and rubble	kg	1
Solid	unspecified	kg	1
Solid	waste	kg	1
Solid	waste bioactive	kg	1
Solid	waste bioactive landfill	kg	1
Solid	waste in incineration	kg	1
Solid	waste in inert landfill	kg	1
Solid	waste limestone	kg	1
Solid	waste to recycling	kg	1
Solid	wood	kg	0
Solid	wood (sawdust)	kg	0
Solid	wood packaging	kg	0
Solid	wood waste	kg	0
Solid	wooden poles	kg	0

1 Bare, Jane C.; Norris, Gregory A.; Pennington, David W.; McKone, Thomas; TRACI, The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts; U.S. EPA; Cincinnati, OH, USA; 2003

Appendix D

Study documents as electronic files in PDF format:

- Appendix D-1:
  Complete study report “Life cycle assessment of office furniture products”
- Appendix D-2:
  Data collection spreadsheets for the later file-, panel-, and work surface product system
- Appendix D-3:
  Complete SimaPro life cycle process flow diagrams for the later file-, panel-, and work surface product system

Life cycle assessment of office furniture products

by
Bernhard A. Dietz

Master thesis in the
University of Michigan
(Natural Resources
and Environment)

Appendix D