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Life-Cycle Assessment of Office Furniture Products

Final report on the study of three Steelcase office furniture

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Final report on the study of three Steelcase office furniture products: Airtouch table, Garland desk, and Siento chair

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Life-Cycle Assessment of Office Furniture Products

Final report on the study of three Steelcase office furniture products:

- AirTouch table
- Garland desk
- Siento chair

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Executive Summary

As part of the continuing effort at Steelcase to introduce environmental product innovations, the University of Michigan Center for Sustainable Systems has conducted a series of life cycle assessment (LCA) demonstration projects. These projects showcase the methods, tools, and results application of LCA for office furniture products. This document provides detailed methods, analysis and results relating to the most recent project – an LCA study of three products.

The three products examined in this study were:

1. Siento chair with polished aluminum base, T-arms, and leather upholstery
2. AirTouch height adjustable table, 30”x 42” straight
3. Garland double pedestal desk with cherry finish, cove edge, left pedestal: file/file, right pedestal: box/box/file

In partnership with Steelcase engineers, the CSS team collected data on product composition, manufacturing processes, distribution and ultimate product disposal. This information was used to construct individual product models in the LCA modeling software SimaPro. The SimaPro model served to combine data from Steelcase engineers with information on materials production and standard processes, and ultimately to calculate LCA results.

Results were compiled in six environmental impact categories: energy resource consumption, global warming potential, acidification potential, criteria pollutants, solid waste, and total material consumption. Results in these categories for the three product systems studied are shown in the Figure below.

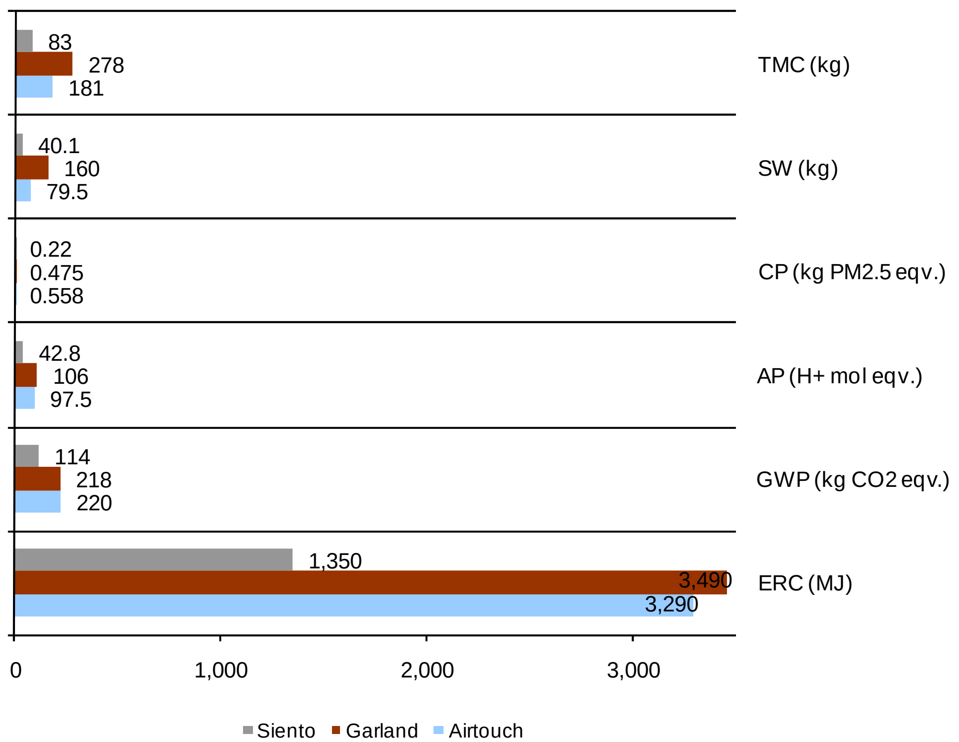

Figure ES-1: Life-Cycle Environmental Impacts per Functional Unit for the AirTouch, Garland, and Siento Product Systems in Comparison; TMC = Total Material Consumption; SW = Solid Waste; CP = Human Health Criteria; AP = Acidification Potential; GWP = Global Warming Potential; ERC = Energy Resource Consumption

In addition, the individual product system results were considered on a per kg basis and normalized to inform observations on the relative importance of material selection verses total product weight. The figure below highlights the differences between the three product systems by showing the results per kg of finished product mass normalized on a scale from 0-1.

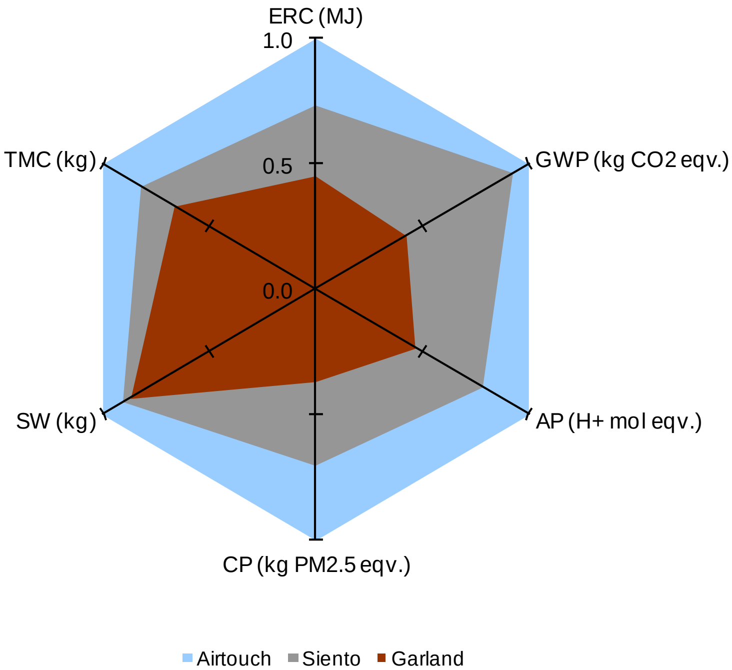

Figure ES-2: Normalized Life-Cycle Impacts per kg of Finished Product for the AirTouch, Garland, and Siento Product Systems in Comparison

The role of specific system parameters in the overall results were further investigated in a sensitivity analysis. Particleboard resin content and extruded aluminum recycling rate were found to be the most significant parameters in determining overall system performance.

Steelcase continues to make significant progress in identifying new opportunities to reduce environmental impacts in both their products and facilities. The judicious use of life-cycle assessment will serve to further this goal while providing a scientifically sound, defensible basis for development of environmental product declarations. Hopefully, LCA will continue to bridge the design, engineering and marketing communities leading to products that inspire customers while reducing environmental impacts.

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1. Introduction/Background

Steelcase recognizes the value of applying life-cycle assessment in design, manufacturing, marketing and product management. In response, Steelcase is pursuing the integration of life-cycle design and assessment tools in support of their core business operations to fully mange products from conception through end of life. The goal of this project is to contribute to product innovation, improvement and external communication of product environmental attributes.

In April 2005, the Center for Sustainable Systems (CSS) at the University of Michigan completed a preliminary life-cycle research project with Steelcase (Dietz 2005). The previous study relied on extensive data collected on site at Steelcase during the summer of 2003 to examine the life-cycle environmental performance of three standard office products (Answer panel, universal file cabinet, and straight-front work surface). This research included comprehensive data collection and modeling well beyond the level of detail for typical life-cycle studies.

The current project uses the data, experience and insight gained over the course of the previous project in combination with data and information on new Steelcase products to develop product-specific streamlined life-cycle inventory models. The detailed understanding of process operations, data sources, and product profiles derived from the previous study enables more efficient collection and analysis of life-cycle inventory data. Existing data on the materials and processes examined in the previous study provide a starting point for this analysis. Additionally, the data collection procedures developed in the previous study provide a foundation for data collection activities implemented here.

1.1. Project Goals/Objectives

Improvement in the environmental performance of office furniture products is a challenging undertaking, due to the diversity of product lines, demanding aesthetic and durability standards, and a customer base with limited knowledge of environmental tradeoffs. The overall goal of this study is to provide a comprehensive view of the life-cycle environmental profile of three Steelcase office furniture products. This assessment should provide the foundation for meaningful consideration of product design alternatives and communication with stakeholders both internally and externally. The specific objectives of the project were to:

- Complete a streamlined life-cycle assessment for three Steelcase products consistent with ISO 14040 standards
- Quantify product environmental performance in easy to understand product information sheets to support environmental declarations
- Highlight product environmental attributes and opportunities for design improvement
- Establish streamlining approaches for future products

1.2. Project Team

This project involved close collaboration between the members of the CSS team who were responsible for model development and data analysis and the members of the Steelcase team who communicated with facility staff, designers, and engineers to obtain information on materials use, energy use, and other product and manufacturing process characteristics. Specific project participants included:

CSS:

David Spitzley, Senior Research Associate
Bernhard Dietz, Research Associate
Gregory Keoleian, Co-Director

Steelcase:

Denise Van Valkenburg, Senior Environmental Engineer
Angela Nihikian, Global Environmental Strategy
Dave Jones, Product Engineer
Dave Walz, Product Engineer
Chris Norman, Product Engineer

2. Approach/Methodology

The study follows life-cycle assessment methodology as codified in the ISO 14040 series standards (ISO 1998) (Keoleian and Spitzley 2005). These standards provide internationally recognized guidelines for the conduct of life-cycle studies. LCA studies conducted under the ISO standards include four activities: goal and scope definition, inventory analysis, impact assessment, and interpretation of results.

2.1. General Scope

This project examines three Steelcase products as discussed below. Each product system encompasses the full product life-cycle including acquisition of all materials from the ground, processing and fabrication of component parts, production and assembly of final product, distribution of materials, parts and final product, product use, and end of life management.

2.2. Products Studied

Three product systems have been selected for the project based on conversations with Steelcase representatives. The selected products address an immediate need for product information, provide valuable examples for development of streamlined approaches, and represent product types likely to have need for future LCA. The three products recommend for the initial investigation are:

4. Siento chair with polished aluminum base, T-arms, and leather upholstery
5. AirTouch height adjustable table, 30”x 42” straight
6. Garland double pedestal desk with cherry finish, cove edge, left pedestal: file/file, right pedestal: box/box/file

Siento Chair

Functional unit: 30 years of ergonomic executive seating in a wood office environment
Reference flow: One Siento chair

A complete parts and materials list for the Siento chair studied is included in Appendix A. A summary of the material composition is shown in Table 2-1.

Table 2-1: Siento Chair Material Composition and Total Product Weight

Material	Weight (lb)
Steel	32.3
Plastic	14.6
Non-ferrous metals	13.4
Leather	2.6
Other	1.7
Total Product Weight	**64.7**

AirTouch

Functional unit: 30 years of flat work space adjustable from 26” to 43” in height while supporting up to 25 lbs.
Reference flow: One AirTouch height adjustable worksurface

A complete parts and materials list for the AirTouch table is included in Appendix B. A summary of the material composition is shown in Table 2-2.

Table 2-2: AirTouch Table Material Composition and Total Product Weight

Material	Weight (lb)
Steel (inc. iron and stainless)	50.4
Particleboard	33.1
Aluminum	28.0
Laminate	3.2
Adhesive and Plastics	1.1
Total Product Weight	**116**

Garland

Functional unit: 30 years of stand alone 72” x 36” work surface use, including storage, in a wood office environment.
Reference flow: One Garland double pedestal desk

A complete parts and materials list for the Garland desk is included in Appendix C. A summary of the material composition is shown in Table 2-3.

Table 2-3: Garland Desk Material Composition and Total Product Weight

Material	Weight (lb)
Particleboard	159.3
Steel	52.9
Plywood	40.2
Cherry	8.6
Other Wood/Paper	3.1
Adhesives and Finishes	1.9
Backing Material	1.6
Plastics	1.5
Total Product Weight	**269**

2.3. System Boundaries

This analysis considers the life-cycle environmental burdens for material acquisition, processing and forming related to parts and materials consistent with accounting for at least 99% of final product composition as reported in Appendices A, B, and C. Product and sub-assembly manufacturing are modeled as discussed in Chapter 2-6. Delivery of materials, parts and final products are included in the system boundary. Although 30 years is taken as the nominal lifetime for all systems studied, no impacts are known to occur during use. End of life collection of discarded furniture and processing of materials is included in the analysis.

2.4. Data Collection Approach

Data were collected by Steelcase representatives' covering four categories of information. Each is discussed below:

Part and Material Composition

This included the collection of information on product assembly structure (e.g. a hierarchal listing or assemblies, sub-assemblies, and parts), part weights assigned at the lowest level of the hierarchy, material composition, and any available information on the forming processes used in part production.

Production Process Equipment Use, Intensity and Yield

This included information on the key assembly and production processes which focused on the equipment use and duration for each process step. Data on electricity, compressed air, and water use were available from the previous study for 17 types of manufacturing equipment used at Steelcase. Information on operating requirements for any equipment not included on the list were collected by Steelcase. Additionally, information on the yield associated with product processing was estimated by Steelcase.

Product Packaging

Information was collected on the packaging types, weight, and material for each product.

Delivery / Product Distribution

Data were collected on the expected sales locations for all of the products studied and weighted delivery distances were calculated accordingly based on location of final assembly.

2.5. Material Data Collection

Material production is expected to play an extremely important role in the overall life-cycle of Steelcase products. Therefore, the collection and analysis of data on the acquisition and processing of materials used in Steelcase products will be discussed in detail in the sections that follow.

In general, existing data related to the production of materials used in Steelcase products are utilized in conducting the LCA of the three products examined here. The use of published data provides two benefits: enhanced efficiency in study conduct and credibility/transparency in data sources. However, data are only used when reasonable values meeting the data quality requirements of the study are available.

Material production data are taken from previous LCA studies of cradle-to-gate operations related to materials provision. The general scope of these studies is shown in the figure below. The studies applied here generally cover processed, unformed materials; however some provide information on formed (molded, cast, stamped, etc.) products.

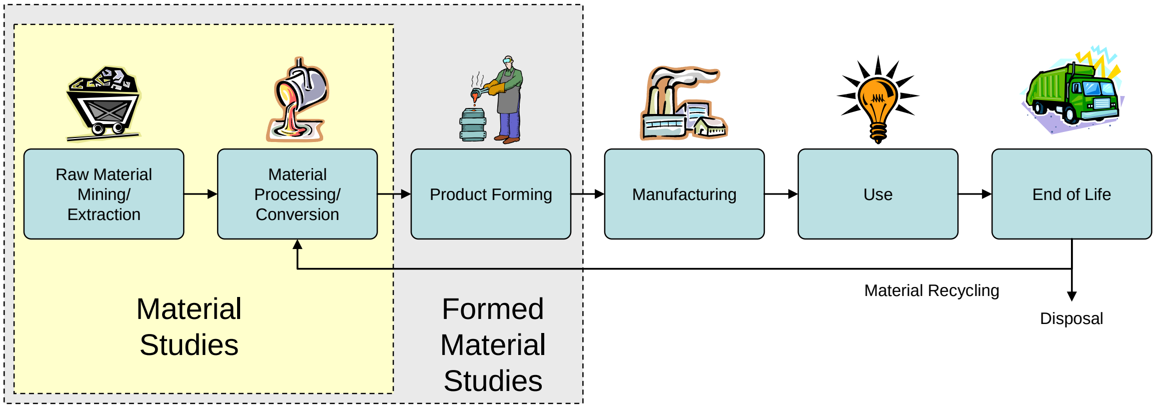

Figure 1: Schematic Depiction of Life-Cycle Approach

The studies referenced here are generally global in nature and reflect a range of production processes and fuel types used throughout the world. While this type of global average data may vary somewhat from data collected for a specific US production plant, the use of global data reflects the increasing commoditization of many materials and the growing importance of international producers. In most cases, international studies reflect the most thorough analysis and most recent data available for the materials studied. Data on average US production operations are expected to vary somewhat from average operations in other countries. Variations in energy use data depend on factors such as technology, age, grid mix and transportation fuel types, but are generally more consistent than data such as air and water pollutant releases. For example, data from a Franklin Associates study in the US in the late 1990's found that plastic bottles (HDPE) required 94.4 MJ/kg for production (Franklin 1998). A European study conducted at the same time found that HDPE bottles required 99.7 MJ/kg, a difference of less than 6% (Bousted 2005).

The data sources, limitations and general data quality for the categories of materials used in the Steelcase LCA are discussed in detail in the sections that follow. Each category of data is discussed in terms of three data quality measures – time, geography and technology – as recommended by ISO 14041 § 5.2.5.

Plastics

Data for plastic materials considered in the analysis of Steelcase products are taken from the reports of the Association of Plastic Manufacturers in Europe (APME) (Bousted 2005). These reports were first published during the period 1993 to 1995 using data from the years 1989 to 1993. Since then, existing reports have been updated and further reports have been added to the list so that there are now sixteen separate reports freely available covering the high volume, bulk polymers, some of the more widely used engineering plastics and some of the standard plastics conversion processes. Data provided by APME were most recently updated in March of 2005.

The APME studies provide current, generic, industry average data with detailed descriptions and a high degree of transparency. However, data are limited to 27 high volume plastics and drawn exclusively from European manufacturing operations. Specific data quality measures are:

- Time: Data are current and have been updated to reflect production practices in place in the period 2003-2005.

- Geography: Data reflect European manufacturing only. However, for some impact categories, such as energy use, plastic production processes in Europe are expected to be similar to those in the US and results may show limited variance from US data as discussed above.
- Technology: Technology used in European plastic production operations is expected to be similar in age and type to that used in the US.

The specific LCI data available from APME covers the polymers, precursors and products shown in Table 2-4 below.

Table 2-4: APME LCI Data Available for Various Polymers

ABS	HDPE resin	PET (extruded, packed)	PVC (bulk resin)
Acetone	Hydrogen (3 routes)	PET (molded)	PVC (calendared sheet)
Acetone cyanohydrin	Hydrogen chloride	Phenol	PVC (extruded film)
Acrylic (dispersion)	Hydrogen cyanide	PMMA beads	PVC (extruded pipe)
Acrylonitrile	LDPE (extruded)	PMMA sheet	PVC (molded)
Ammonia	LDPE (molded)	Polybutadiene	PVC (resin emulsion)
Benzene	LDPE resin	Polycarbonate	PVC (resin suspension)
Brine	LLDPE resin	Polyols	Pyrolysis gasoline
Butadiene	MDI	Polypropylene	Sodium hydroxide
Butenes	Methylmethacrylate (MMA)	Polypropylene (extruded)	Steam
Chlorine	Naphtha	Polypropylene (molded)	Styrene
Crude Oil	Natural gas	Polystyrene (expandable)	Styrene Butadiene (dispers.)
Electricity	Nylon 6	Polystyrene (general purpose)	Styrene-Acrylonitrile
Epoxy liquid resins	Nylon 6 (glass filled)	Polystyrene (high impact)	TDI
Ethylbenzene	Nylon 66	Polystyrene (thermofoam)	Terephthalic Acid
Ethylene	Nylon 66 (glass filled)	Polyurethane (flexible foam)	Toluene
Ethylene (pipeline)	Pentane	Polyurethane (rigid foam)	Vinyl Acetate (dispersion)
Ethylene Dichloride	PET (amorphous)	Polyvinylidene chloride (PVC)	Vinyl Chloride Monomer
HDPE (extruded)	PET (bottle grade)	Propylene	Xylenes
HDPE (molded)	PET (extruded)	Propylene (pipeline)	

Steel

Global average data for the production of steel are taken from studies conducted by the International Iron and Steel Institute (IISI) (IISI 2002). IISI conducted surveys of member companies to establish accurate worldwide LCI data for steel industry products based on practices in place between 1999 and 2000. Data available from IISI cover 14 conventional steel produced in two manufacturing processes (basic oxygen furnace (BOF) and electric arc furnace (EAF)) and two types of stainless steel.

The IISI studies provide current, global, industry average data. Although North American facilities were included in the data collection process, separate data are not available for competitive reasons. A comparison of global average data from IISI for cold rolled steel with North American data collected in the early 1990's for the USAMP generic vehicle study (not publicly available) indicates that both provide an identical value for energy use of 28 MJ/kg. This suggests global average data and North American data may show only minor differences in terms of the key indicator of energy use. Specific data quality measures are:

- Time: Data are relatively current, given the low rate of capital turnover in the steel industry, and reflect production practices in place in the period 1999-2000.

- Geography: Data reflect global average manufacturing. North American data are included in this average.
- Technology: Data available cover both major steel production processes (BOF and EAF). Steel production technology is expected to show limited variability globally.

The specific LCI data available from IISI covers the steel types and products shown in Table 2-5 (unless otherwise specified steels are produced via BOF).

Table 2-5: IISI LCI Data Available for Various Steel Products

Cold Rolled Coil	Hot Rolled Coil	Rebar/Wire Rod (BOF)	Stainless (316-2B)
Electro-galvanized	Hot-dip Galvanized	Rebar/Wire Rod (EAF)	Tin-free Steel
Engineering Steel (BOF)	Organic Coated Flats	Sections (BOF)	Tinplated Products
Engineering Steel (EAF)	Pickled Hot Rolled Coil	Sections (EAF)	Welded Pipes
Finished Cold Rolled Coil	Plate	Stainless (304-2B)	

Wood Products

Data for a number of common wood projects used in building and construction have been compiled by the Consortium for Research on Renewable Industrial Materials (CORRIM) (Wilson and Sakimoto 2004). This research covers many typical wood products such as dimensional lumber, oriented strand board, plywood, etc. However, no data specific to the production of particle board such as that used by Steelcase in the production of casework and worksurfaces are provided. CORRIM has initiated a second phase of research examining the production of particle board in the United States. Results are expected from the second phase of research in the summer of 2006. CORRIM has agreed to provide the specific results to the project as soon as they are available. In the meantime, we will proceed to compile available CORRIM data and other information as a basis for an approximate model of particleboard production.

Particleboard is modeled in the Steelcase project assuming the final particleboard is composed of 9.5% urea-formaldehyde resin and 90.5% saw dust and other wood wastes (Mari 1983). Wood waste products have no burdens associated with their use as a raw material; all impacts are allocated to other timber products. LCI data for the production of the chemical products Urea and Formaldehyde come from data available in SimaPro on the manufacture of chemicals in Europe. Energy use and wood waste data from CORRIM related to the pressing and trimming of plywood are used a surrogates for the same operations in the production of particleboard.

Cherry wood used in surface veneer and edging is modeled using data for the harvesting of Ash trees in Europe. Cherry and ash trees have similar physical properties, e.g. specific gravity, static bending properties, and side hardness (AIA 2005) and production data were adjusted to reflect the average US electrical grid and US trailer transport. Logs are transported 966 km (600 miles) from the Eastern US to Grand Rapids. Energy use and waste data associated with the production of veneer from logs was taken from CORRIM data for the production of veneer for plywood production. An adjustment was made for the difference between the veneer peeling process used for plywood and the slicing process used for Steelcase veneer[1]. The slicing process does not result in core waste as is the case for the peeling process.

Specific data quality measures are:

- Time: Data from CORRIM are current, other data sources are likely older. Specifically, the most recent discussion of the proportion of resin in particleboard is from the early 1980's and resin management has changed significantly over the past 20 years.
- Geography: Data taken from CORRIM reflect typical North American conditions, data taken from European databases for Urea, Formaldehyde, and Ash harvesting have been adjusted so that key energy process reflect US conditions. However, for these materials, data not related to energy infrastructure are expected to differ from typical US values.
- Technology: Data used provide poor technological relevance. Plywood pressing data have been used as surrogate for particleboard pressing and peeling data have been substituted for peeling data in the veneer production process.

Aluminum

North American average data for the production of aluminum products such as those used in the automotive industry are taken from a study conducted by the Aluminum Association (Aluminum Association 1998). These data were compiled for the US Automotive Materials Partnership life-cycle inventory project. Data are provided for three categories of typical automotive aluminum products: shape cast, rolled sheet, and extruded.

Formed product data are provided by the Aluminum Association for 100% secondary content, 100% primary content, and present industry practice (11% secondary content in rolled and extruded products, 85% secondary content in cast products). Data for 100% primary and 100% secondary content were input to the model to allow the modeling of varying levels of recycled content. A conversation with a representative of the Aluminum industry confirmed that typical recycled content for aluminum products across multiple industries is still expected to be similar to the values reported for 1995. Therefore, cast aluminum products were modeled with a recycled content of 85% while rolled and extruded products were modeled with a recycled content of 11%. The sensitivity of results to this assumption is examined in the results section.

Specific data quality measures are:

- Time: Data reflect a 1995 study of the aluminum industry. Few changes are expected to have taken place in the North American aluminum industry in the past decade.
- Geography: Data reflect typical North American operations.
- Technology: Data reflect processes and recycling rates found in a study of automotive aluminum suppliers. However, conversations with an industry representative confirmed that few technological differences are expected between aluminum production for the automotive industry and production for the office furniture industry.

[1] According to CORRIM data, log cores result in 0.07 lbs of wood waste per 1.0 lb of dry veneer produced. This waste was not included in the analysis, thus the quantity of veneer produced in the process was increased by 0.07 lbs.

Other Material Data

Data for other materials used in the production of Steelcase products were taken from databases available in SimaPro. When data from non-North American sources were used, the relevant energy systems were updated to reflect more typical US conditions as reported by Franklin Associates. Generally, these materials include miscellaneous chemicals (e.g. adhesives), fabrics (e.g. polyester), and alloying metals (e.g. magnesium). Data quality measures will very depending on the specific data set, however, overall data quality for these materials is expected to be lower than for other data sources.

2.6. Manufacturing Modeling

The previous analysis of Steelcase products indicated that final manufacturing processes contributed 6% - 16%[2] of the total life-cycle burden for office furniture products. The previous analysis further indicated that less than 0.5% of total life-cycle burdens were related to overhead energy use in manufacturing facilities[3]. No data to support the assessment of manufacturing overheads were available in this study and these operations were neglected in the present analysis.

This analysis used a streamlined approach to consideration of manufacturing inventory results. Manufacturing / production process in place in Steelcase facilities, and in some cases at contract manufacturers, were modeled by first examining the machine operating time required for each process step as provided by Steelcase. This information was combined with data on electricity, compressed air, and cooling water required per unit operating time to estimate production requirements. Table 2-6 provides an example of the process time data, while Table 2-7 provides the equipment data used in the study.

Table 2-6: Drawer Headset Production Process, time and equipment requirements by step (process with no equipment use have been removed from list)

Process Step	Time (sec./part)	Equipment Used
Make Face	7.9	Splicer
Cut to Size	0.04	Tenoner
Press-Wemhoener	15.1	Hot-laminating press (wood)
Cut Net Width	28.8	Table saw
Cut Net Length	28.8	Table saw
Band 2 ps	93.8	Tenoner
Split per dwg	71.3	Tenoner
Band 4ps	168.8	Tenoner
CMS#7	270.2	CNC router (wood)
Rgh&Fine Sand FC	252.0	Sanding

[2] Results for energy use, other impact categories followed a similar pattern.
[3] Methodology applied in the previous study accounted for overhead related to equipment operating time and did not account for overhead when equipment was not in use. This likely understates the total overhead burden.

Finish Prep	394.1	Hand tools
Finish per Spec	9.3	Finishing

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

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

Equipment operating requirements were input into SimaPro and combined with data on US average electricity production, compressor operation, and potable water production to calculate inventory results for the manufacturing stage.

In addition, data available on the efficiency of operational stages were taken into account in the analysis. Processing yields provided by Steelcase for use in this analysis were as follows:

- Finish wood processing (veneer and edging) – Overall wood plant processing losses of 70% of input material were included in the analysis based on conversation with Steelcase.
- Leather upholstery – cutting and trimming losses associated with chair upholstery were estimated as 40% of input material.

2.7. Distribution Modeling

Distribution was specifically modeled in SimaPro for two activities – the movement of massive parts and sub-assemblies to the production location and delivery of finished product to customers. Movement of materials is included in the raw material data sets that served as the source for material production data.

Massive parts and sub-assemblies were defined as those parts described in data provided by Steelcase as contributing more than 5% of the finished product mass. The specific parts included in the distribution model are shown in Table 2-8 below.

Table 2-8: Parts Considered in Product Distribution Model, (a) For Garland, materials weighing more than 5% of the finished product weight at the time of delivery (prior to manufacturing losses) were included in the distribution model

Product	Parts Modeled (Wt. in lb)
AirTouch	Particleboard (33.1)
	Column, inner + outer extrusion (23.2)
	Tube support (13.96)
	Curved plate (8.96)
	Mounting plates (two plates) (11.86)
Siento	Polished aluminum base (6)
Garland[(a)]	Particleboard (159.3)
	Veneer (14.3)
	Plywood drawers (six drawers) (40.2)

Delivery distances for these parts are shown in Table 2-9.

Table 2-9: Delivery Distances for Product Parts; (a) products produced in-house at the final assembly location

Product	Part	Starting Point	Ending Point	Miles
AirTouch	Particleb. Cores	Wood Products Manufacturer (Western US)	Part Supplier (Tijuana, Mexico)	993
AirTouch	Column Extrusions	Aluminum Products Manufacturer (Eastern US)	Metal Fabricator (Juarez, Mexico)	2,380
AirTouch	Tube support	Metal Fabricator (Grand Rapids, MI)	Metal Fabricator (Grand Rapids, MI)	(a)
AirTouch	Curved plate	Metal Fabricator (Grand Rapids, MI)	Metal Fabricator (Grand Rapids, MI)	(a)
AirTouch	Mounting plates	Metal Fabricator (Grand Rapids, MI)	Metal Fabricator (Juarez, Mexico)	1,804
Siento	Base	Part Fabricator (China)	Shipping Port (Los Angeles, CA)	6,260
Siento	Base	Shipping Port (Los Angeles, CA)	Brayton (High Point, NC)	2,460
Garland	Particleboard Cores	Wood Products Manufacturer (Western US)	Steelcase (Grand Rapids, MI)	2,400
Garland	Veneer	Eastern US	Steelcase (Grand Rapids, MI)	600
Garland	Plywood Drawers	Unknown Supplier (Grand Rapids, MI)	Steelcase (Grand Rapids, MI)	Neg.

For the AirTouch product, three separate assemblies are produced by individual suppliers and are consolidated in a single location prior to customer delivery. This product consolidation is modeled as part of the life-cycle. The worksurface is produced by part supplier in Tijuana, Mexico; the central column is produced by a metal fabricator in Juarez, Mexico and the base is produced by a metal fabricator in Grand Rapids, Michigan. The product is consolidated at the Steelcase facility in City of Industry, California. Table 2-10 below provides the data used in the distribution model for these shipments.

Table 2-10: Weight and Distance for AirTouch Shipments to City of Industry, California

Assembly	Wt. (lb)	Source Location	Miles
Worksurface	51.2	Part Supplier (Tijuana, Mexico)	130
Column	47.5	Metal Fabricator (Juarez, Mexico)	787
Base	37.1	Metal Fabricator (Grand Rapids, MI)	2,170

Final product deliveries were modeled according to general information provided by Steelcase on the expected volume for major customer locations. For the AirTouch product, 80% of customer deliveries went to the largest cities on the US West Coast (with an average delivery distance of 266 miles), the remaining 20% of deliveries went to the remaining largest cities in the US (with an average delivery distance of 2280 miles)[4].

The Siento and Garland products are expected to follow similar customer delivery patterns. The Garland product ships from Grand Rapids, Michigan while the Siento product ships from Brayton in High Point, North Carolina. Customer deliveries are distributed across the country according to the data shown in Table 2-11 below.

Table 2-11: Product Delivery Distances for Garland and Siento Products

	Delivery Distance (miles)		
Customer Location	**Market Share**	**Garland**	**Siento**
NY Customers	35%	747	560
Atlanta Customers	7%	827	321
Ohio Customers	6%	323	395
Washington, DC Customers	6%	658	325
Chicago Customers	5%	180	776
Detroit Customers	5%	158	639
Boston Customers	5%	843	775
Other US Customers	31%	1,650	1,760

All deliveries are assumed to use diesel trailers for the full shipment distance. Data from Franklin Associates on diesel trailer transport are used in the SimaPro model.

4 Population weighted average distance from City of Industry, CA to New York, NY, Chicago, IL, Washington, D.C., Boston, MA, Detroit, MI, Atlanta, GA, and Cleveland, OH.

2.8. End of Life Modeling

Material management at the product end-of-life has been modeled according to US EPA data (Municipal Solid Waste in the United States; October 2003, Washington D.C.) Specific recovery rates for different materials are derived from data on durable goods (incl. appliances) as well as packaging and containers. Remaining waste after material recovery is either combusted or landfilled at rates of 14.7% and 55.7% respectively. 29.6% of the remaining waste is directed towards unknown waste treatment. Table Y-2 shows the specific recovery rates for various materials.

Although these data represent the appropriate national average category (durable goods) for US management of unspecified office furniture waste, they likely provide an unrealistic portrayal of office furniture end of life management. Durable goods in the US waste stream include large and small appliances, furniture and furnishings, carpets and rugs, rubber tires, automotive batteries, and consumer electronics among other items. It is likely that office furniture represent a relatively small percentage of the overall durable goods waste stream. Ideally, data specific to the management of office furniture products would be substituted for the more general durable goods data, however, no such data are available at this time.

Table 2-12 shows the end-of-life waste management scenario based on EPA data for durable goods in municipal solid waste.

Table 2-12: End-of-life waste management scenario based on EPA data for durable goods in municipal solid waste

Material in Waste Stream	Recovery Rate	Comment
Ferro metals	28%	
Copper	60%	
Magnesium	60%	
Zinc	60%	
Aluminum	0%	According to source negligible for durable goods
Non-ferro metals (others)	60%	
Glass	0%	According to source negligible for durable goods
Polyethylene (PE)	5.5%	
Polyethylene terephthalate (PET)	5.5%	
Polypropylene (PP)	5.5%	
Polyvinylchloride (PVC)	5.5%	
Plastics (others)	5.5%	
Wood	15%	According to source for containers and packaging
Paper	55%	According to source for containers and packaging
Cardboard	55%	According to source for containers and packaging

2.9. Impact Assessment Methodology

In this study, we use the characterization factors developed by the US EPA as part of the tool for the reduction and assessment of chemical and other environmental impacts (TRACI) to evaluate impacts using a US-focused framework. This is especially important for impact categories that are expected to show strong geographic and demographic variance (e.g. acidification, human health criteria). Relevant characterization factors from TRACI are provided in the section that follows.

The impact assessment categories, listed below, are evaluated according to the impact assessment methods described in the paragraphs that follow each category.

Energy/Energy Resource Consumption (e.g. Mega Joules, MJ)

Much of the energy used by society today is derived from resources available in a finite supply (~94% in the U.S.). Once exhausted, these resources will no longer be available to support the basic needs of future generations. Sustainable energy requires a shift from limited fossil fuels towards renewable energy technologies. This category captures the primary energy content of non-renewable fuels used throughout the life-cycle. Primary energy content is calculated here using the lower heating value (LHV) of energy resources. Lower heating value is determined by considering water produced during combustion as steam. The evaluation of impacts in this category requires information on the properties of fuels consumed and thus does not rely on the TRACI methodology.

Table 2-13: Example Characterization Factor Data (MJ primary energy consumption/kg material consumption)

Fuel	Energy Cons. (MJ)
Coal	26.4
Crude oil	42.0
Natural gas	46.8
Uranium	2,291,000.0

Global Warming (e.g. kg Carbon Dioxide Equivalents, kg CO_2 eqv.)

Global climate change is one of the most pressing environmental challenges of the 21st Century. Greenhouse gas emissions resulting from anthropogenic activities over the past two centuries have led to an accelerating build-up of heat-trapping gases in the atmosphere. Climate change can have severe impacts on life sustaining systems including water resources, agriculture, human settlements, and human health. In this metric, the global warming potential (GWP) for each pollutant known to be a greenhouse gas is used to normalize emissions quantities into a single value. The GWP is a measure of the relative radiative effect for a given greenhouse gas referenced to carbon dioxide (CO_2). Values proposed by the Intergovernmental Panel on Climate Change are widely accepted in the scientific community and are used in TRACI.

Table 2-14: Example Characterization Factor Data (kg CO_2 equivalents/kg emission)

Emission	GWP (kg CO_2 eqv.)
CO_2	1
Methane	23
N_2O	296

Acidification (e.g. Moles of Hydrogen Ion Equivalents, H^+ mol eqv.)

Acidification provides a measure of the potential increase in acidity (expressed in hydrogen ion concentration) of water and soil systems as a result of emissions associated with the life-cycle of a product. Acidifying emissions result in ecosystem damages in lakes and have corrosive effects on buildings and structures. Relative acidification potential of pollutants is assigned based on methodology proposed for the TRACI program. TRACI provides US-specific characterization factors for known acidifying pollutants.

Table 2-15: Example Characterization Factor Data (mol H^+ equivalent/kg emission)

Emission	AP (kg H^+ mol eqv.)
NH_3	95.5
HCl	44.7
NO_x	40.0
SO_x	50.8

Human Health Criteria (kg Equivalent to Particulate Matter Less than 2.5 Micro-Meters in Diameter, kg $PM_{2.5}$ eqv.)

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, each pollutant is assigned a weighting based on the health effects of inhalation relative to $PM_{2.5}$. The values shown in
Table 2-16 are the characterization factors used here.

Table 2-16: Example Characterization Factor Data (kg $PM_{2.5}$ equivalents/kg emission)

Emission	CP (kg $PM_{2.5}$ eqv.)
NO_x	0.041
Particulates (PM_{10})	0.6
Particulates ($PM_{2.5}$)	1
Particulates (unspecified)	0.33
SO_x	0.240

Material Consumption/Resource Depletion (kg)

Raw materials are extracted from the earth for conversion into engineered materials, commodity materials, and for use in products. Many of the materials extracted are non-renewable and their use contributes to the continued decline of reserves. Recycling and reuse of materials is one strategy for mitigating the need for additional raw material extraction. This metric provides an overall sum of non-fuel materials extracted from the earth. Water is not considered a material for the purposes of this calculation. No characterization is required for this evaluation (no well accepted impact assessment methods are available for this category).

Solid Waste (kg)

The impact category "solid waste" compiles product system related wastes, which are unsuitable for reuse and recycling, and are either landfilled or incinerated. Solid waste comprises various residues from the raw material provision, manufacturing, usage, and product retirement phases. Solid waste is not characterized, but rather is reported as the sum of total waste material.

3. Results

The sections below provide life-cycle results for the product systems studied.

3.1. Siento

Selected life-cycle inventory results for the functional unit of one Siento chair are shown in Table 3-1. Full life-cycle inventory results for this product system are available in Appendix D.

Table 3-1: Selected Life-Cycle Inventory Results for the Siento Product System (kg/Siento chair)

Category/Substance	Qty. (kg)
Material Consumption	
Iron	13.9
Coal	11.2
Crude oil	10.4
Aluminum scrap	10.2
Steel scrap	7.6
Bauxite	4.1
Natural gas	2.6
Air Emissions	
CO2	106.8
CO	0.4
SOx	0.3
Methane	0.2
NOx	0.2
Effluents	
COD	0.05
BOD	0.01
Solid Waste	
Total waste	58.2

The flow diagram shown in Figure 2 indicates the relative contribution of individual processes to the overall life-cycle impacts of the Siento product system in the category of energy use. The line thickness indicates the relative importance of each step and the percentages shown indicate the contribution to the total system life-cycle. Figure 3 provides the same information in the category of criteria pollutants. Note, for both diagrams only process contributing more than 5% of the total life-cycle burden are shown.

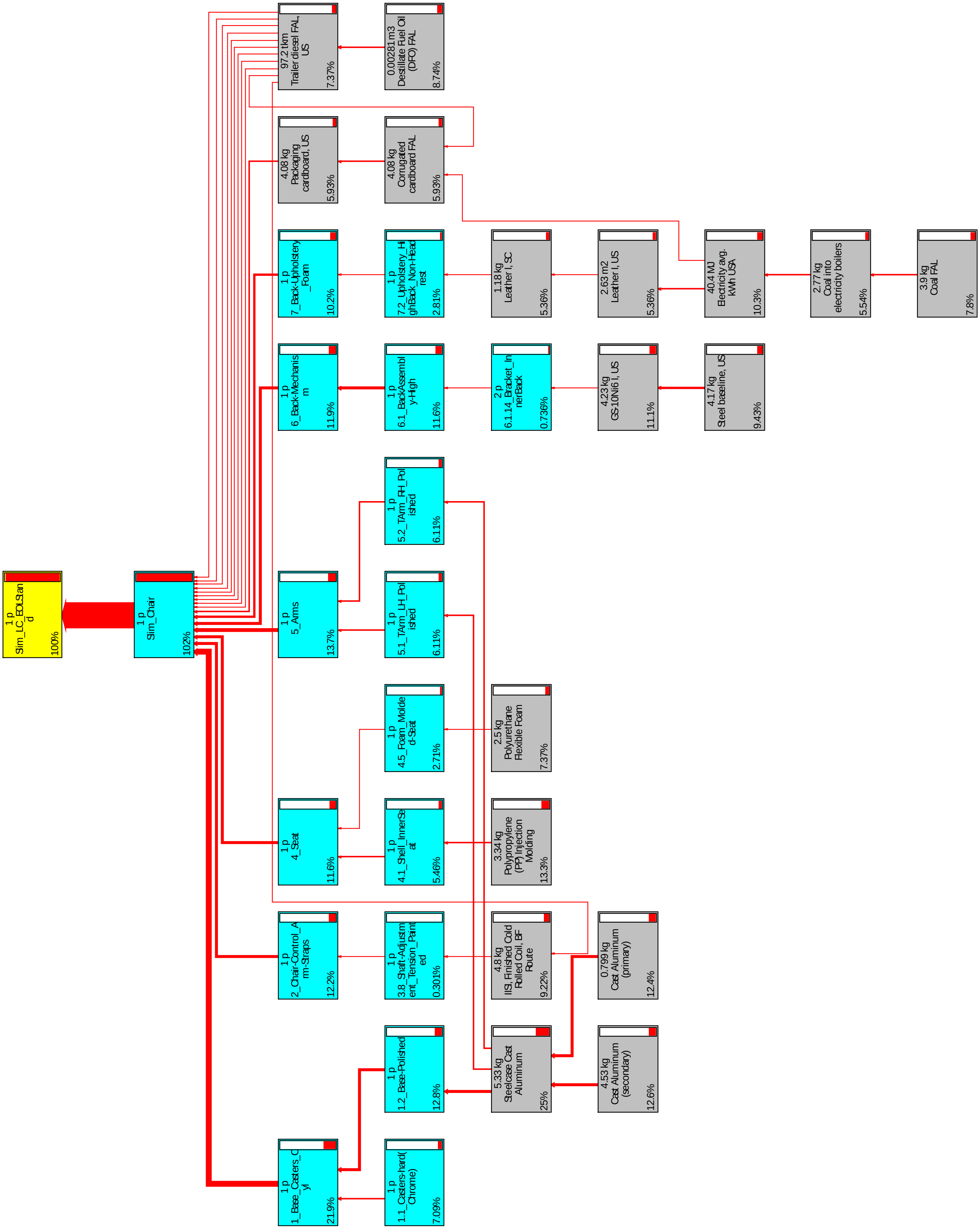

Figure 2: Relative Contribution of Individual Processes to the Overall Life-Cycle Impacts of the Siento Product System in the Category of Energy Use

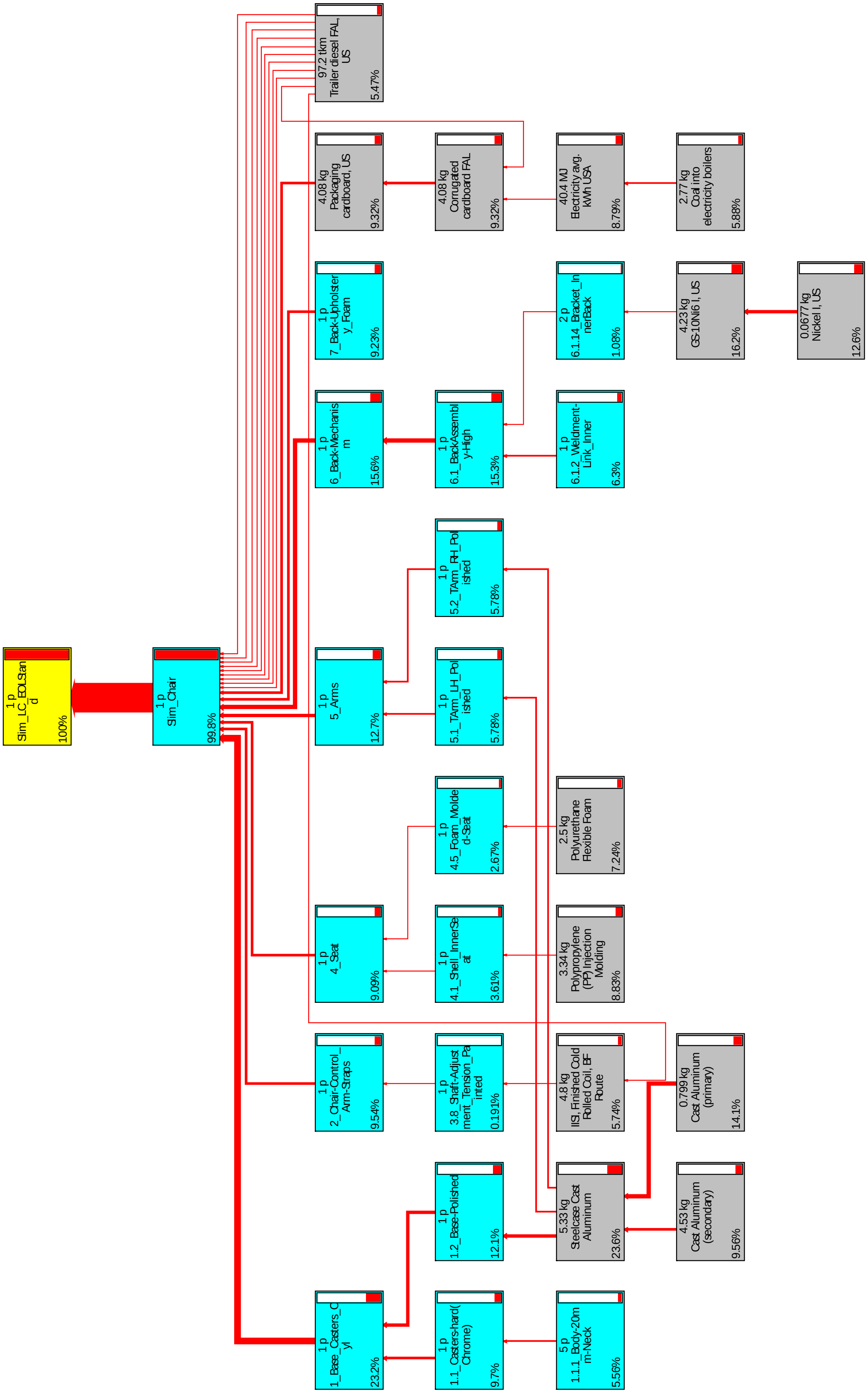
1 p Slim_LC_EOLStand 100%
1 p Slim_Chair 99.8%
97.2 tkm Trailer diesel FAL, US 5.47%
4.08 kg Packaging cardboard, US 9.32%
4.08 kg Corrugated cardboard FAL 9.32%
40.4 MJ Electricity avg. kWh USA 8.79%
2.77 kg Coal into electricity boilers 5.88%
1 p 7_Back-Upholstery_Foam 9.23%
2 p 6.1.14_Bracket_InnerBack 1.08%
4.23 kg GS-10Ni6 I, US 16.2%
0.0677 kg Nickel I, US 12.6%
1 p 6_Back-Mechanism 15.6%
1 p 6.1_BackAssembly-High 15.3%
1 p 6.1.2_Weldment-Link_Inner 6.3%
1 p 5.2_TArm_RH_Polished 5.78%
1 p 5_Arms 12.7%
1 p 5.1_TArm_LH_Polished 5.78%
1 p 4.5_Foam_Molded-Seat 2.67%
2.5 kg Polyurethane Flexible Foam 7.24%
1 p 4_Seat 9.09%
1 p 4.1_Shell_InnerSeat 3.61%
3.34 kg Polypropylene (PP) Injection Molding 8.83%
1 p 2_Chair-Control_Arm-Straps 9.54%
1 p 3.8_Shaft-Adjustment_Tension_Painted 0.191%
4.8 kg IISI, Finished Cold Rolled Coil, BF Route 5.74%
0.799 kg Cast Aluminum (primary) 14.1%
1 p 1.2_Base-Polished 12.1%
5.33 kg Steelcase Cast Aluminum 23.6%
4.53 kg Cast Aluminum (secondary) 9.56%
1 p 1_Base_Casters_Cyl 23.2%
1 p 1.1_Casters-hard(Chrome) 9.7%
5 p 1.1.1_Body-20mm-Neck 5.56%

Figure 3: Relative Contribution of Individual Processes to the Overall Life-Cycle Impacts of the Siento Product System in the Category of Human Health Criteria

Table 3-2 and Figure 4 provide the overall life-cycle impacts for the Siento product system in the six impact categories selected.

Table 3-2: Life-Cycle Environmental Impacts for the Siento Product System

Impact Category	Unit	Impact
Energy resource consumption	MJ	1,350
Global warming potential	kg CO_2 eqv.	114
Acidification potential	H^+ mol eqv.	42.8
Criteria pollutants/human health	kg $PM_{2.5}$ eqv.	0.22
Solid waste (excl. recyclables)	kg	40
Total material consumption	kg	83

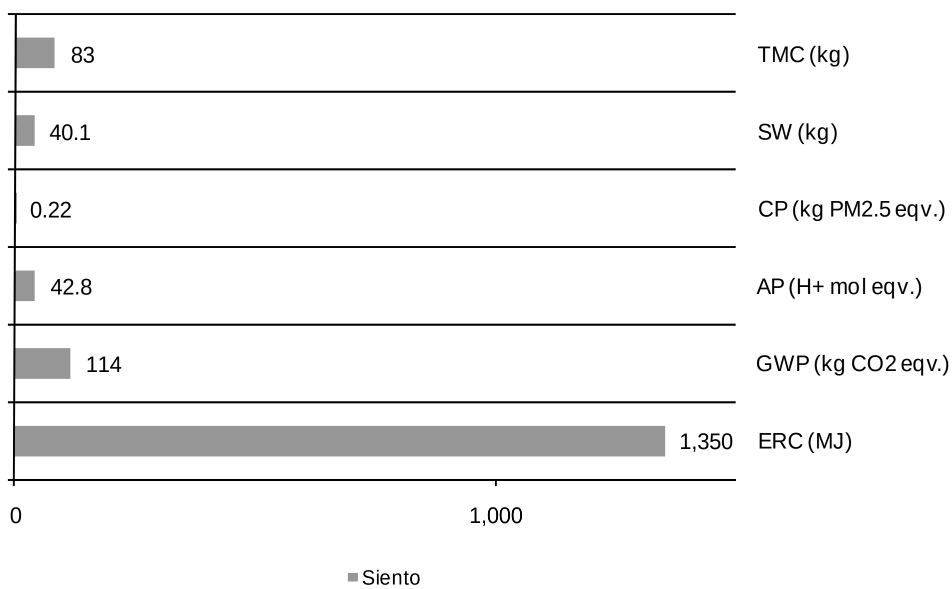

Figure 4: Life-Cycle Environmental Impacts for the Siento Product System; TMC = Total Material Consumption; SW = Solid Waste; CP = Human Health Criteria; AP = Acidification Potential; GWP = Global Warming Potential; ERC = Energy Resource Consumption

3.2. Garland

Selected life-cycle inventory results for the functional unit of one Garland desk are shown in Table 3-3. Full life-cycle inventory results for this product system are available in Appendix E.

Table 3-3: Selected Life-Cycle Inventory Results for the Garland Product System (kg/desk)

Category/Substance	Qty. (kg)
Material Consumption	
Wood (all types)/ wood waste	144.2
Coal	44.1
Crude oil	22.8
Natural gas	22.2
Air Emissions	
CO2	220.8
SOx	1.3
CO	1.2
NOx	0.8
Methane	0.3
Effluents	
COD	0.06
BOD	0.01
Solid Waste	
Total waste	189.5

The flow diagram shown in Figure 5 indicates the relative contribution of individual processes to the overall life-cycle impacts of the Garland product system in the category of energy use. The line thickness indicates the relative importance of each step and the percentages shown indicate the contribution to the total system life-cycle. Figure 6 provides the some information in the category of criteria pollutants. Note, for both diagrams only process contributing more than 5% of the total life-cycle burden are shown.

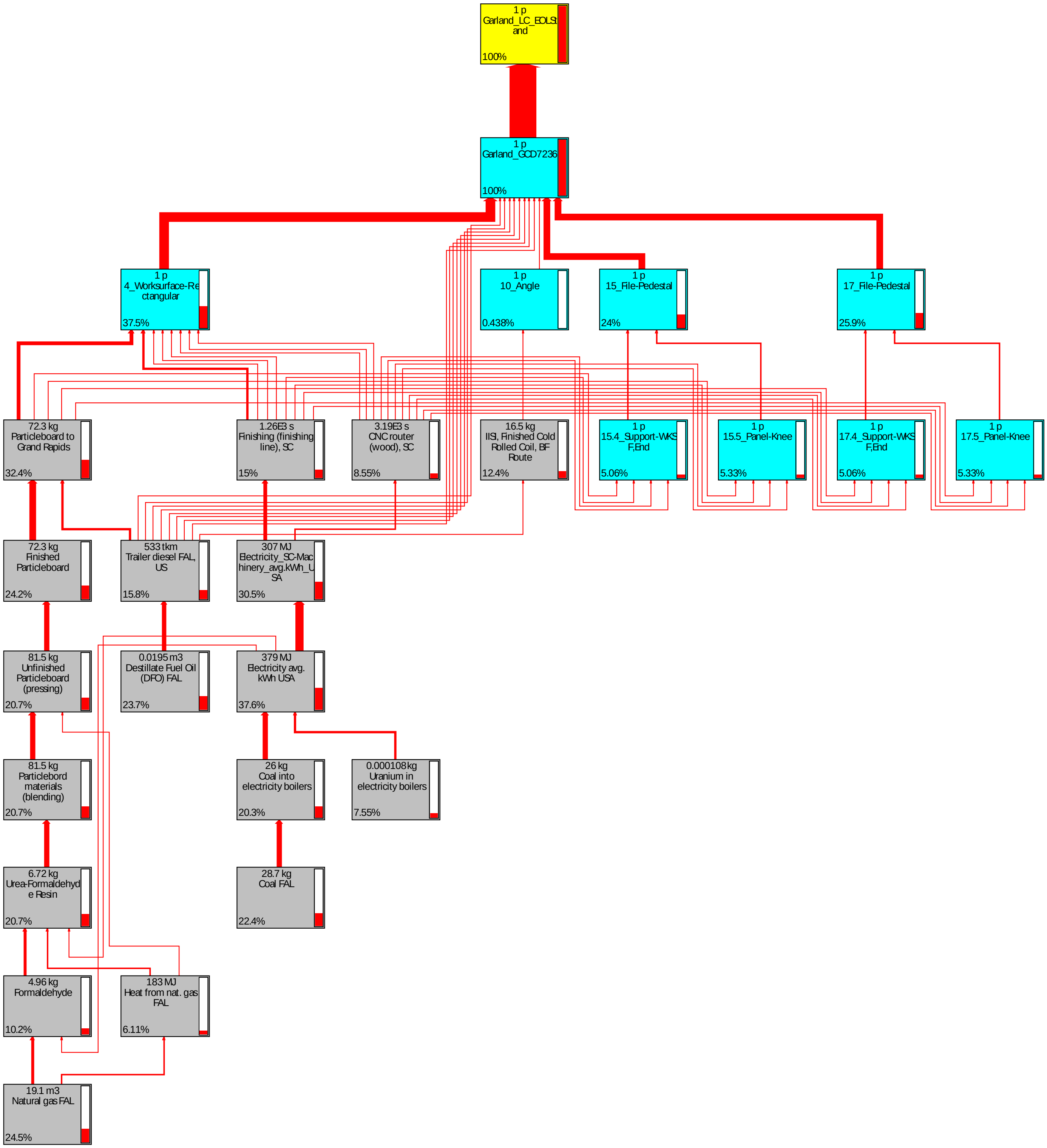

Figure 5: Relative Contribution of Individual Processes to the Overall Life-Cycle Impacts of the Garland Product System in the Category of Energy Use

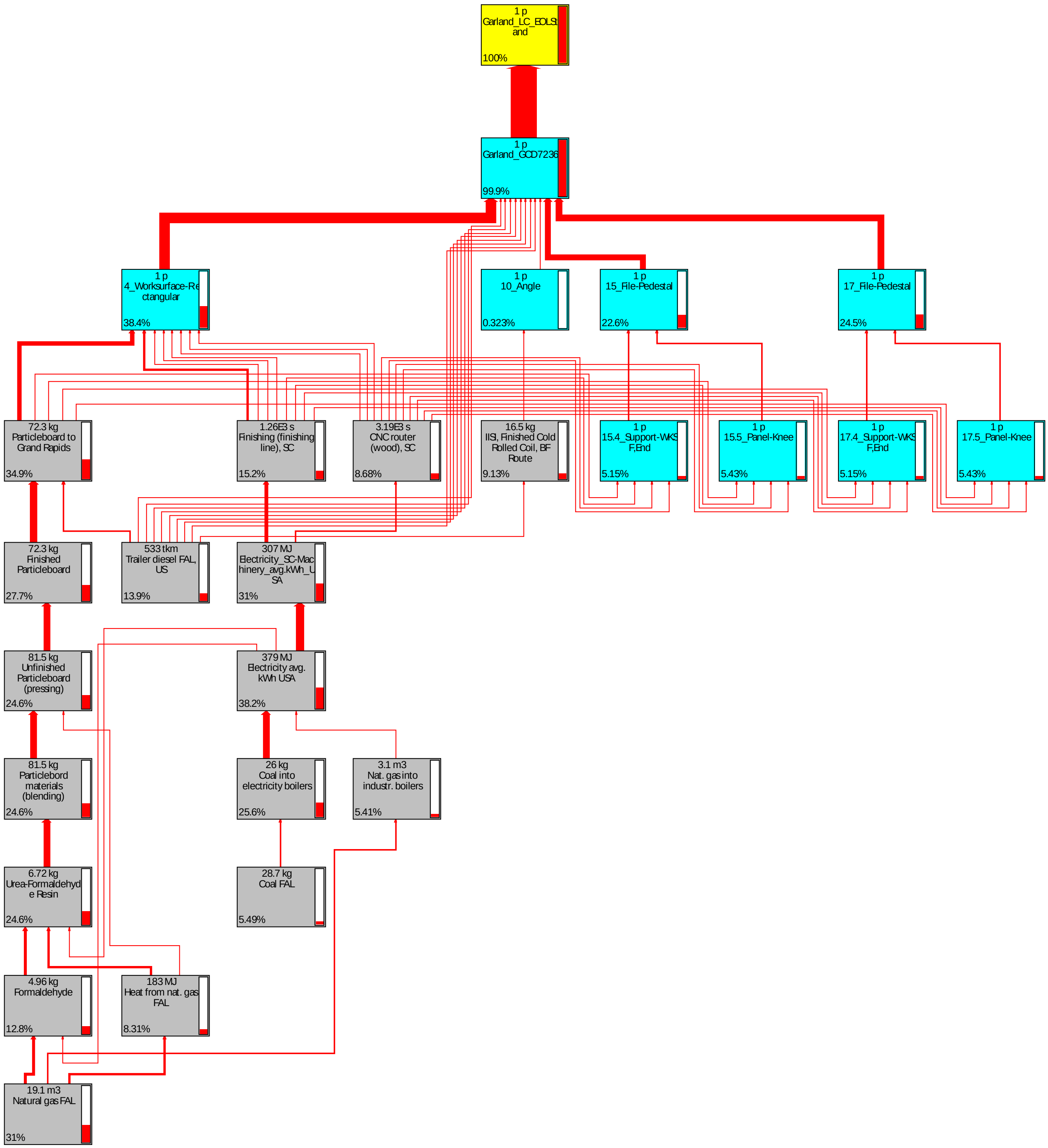

Figure 6: Relative Contribution of Individual Processes to the Overall Life-Cycle Impacts of the Garland Product System in the Category of Human Health Criteria

Table 3-4 and Figure 7 provide the overall life-cycle impacts for the Garland product system in the six impact categories selected.

Table 3-4: Life-Cycle Environmental Impacts for the Garland Product System

Impact Category	Unit	Impact
Energy resource consumption	MJ	3,452
Global warming potential	kg CO_2 eqv.	218
Acidification potential	H^+ mol eqv.	106
Criteria pollutants/human health	kg $PM_{2.5}$ eqv.	0.48
Solid waste (excl. recyclables)	kg	160
Total material consumption	kg	836

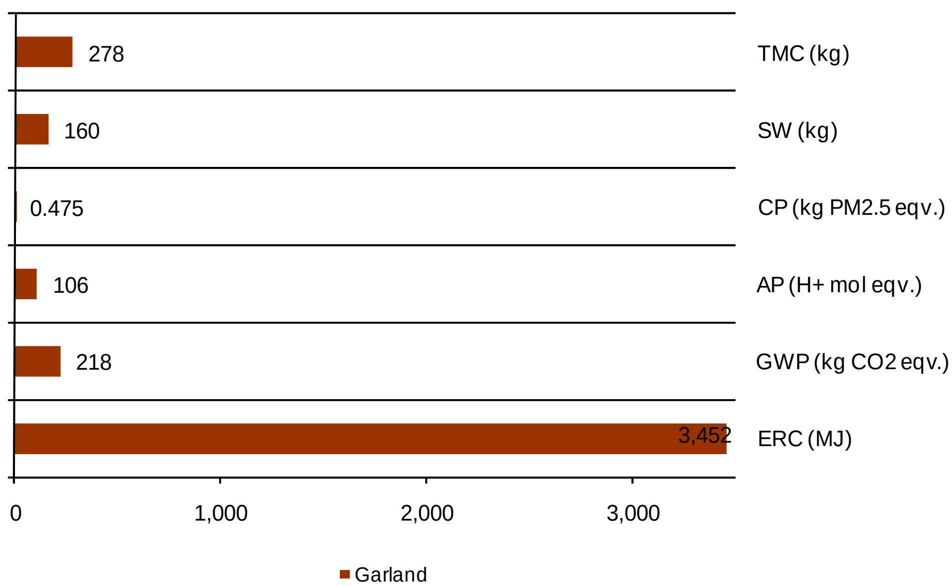

Figure 7: Life-Cycle Environmental Impacts for the Garland Product System; TMC = Total Material Consumption;
SW = Solid Waste; CP = Human Health Criteria; AP = Acidification Potential; GWP = Global Warming Potential; ERC = Energy Resource Consumption

3.3. AirTouch

Selected life-cycle inventory results for the functional unit of one AirTouch table are shown in Table 3-5. Full life-cycle inventory results for this product system are available in Appendix F.

Table 3-5: Selected Life-Cycle Inventory Results for the AirTouch Product System (kg/table)

Category/Substance	Qty. (kg)
Material Consumption	
Bauxite	51.6
Iron	27.6
Wood / Wood Waste	24.8
Steel Scrap	20.3
Coal	15.7
Crude Oil	9.0
Natural Gas	7.4
Aluminum Scrap	4.0
Air Emissions	
CO_2	215.0
CO	1.6
SO_x	1.3
NO_x	0.7
Methane	0.1
Effluents	
COD	0.04
BOD	0.01
Solid Waste	
Total waste	142.3

The flow diagram shown in Figure 8 indicates the relative contribution of individual processes to the overall life-cycle impacts of the AirTouch product system in the category of energy use. The line thickness indicates the relative importance of each step and the percentages shown indicate the contribution to the total system life-cycle. Figure 9 provides the some information in the category of criteria pollutants. Note, for both diagrams only process contributing more than 5% of the total life-cycle burden are shown.

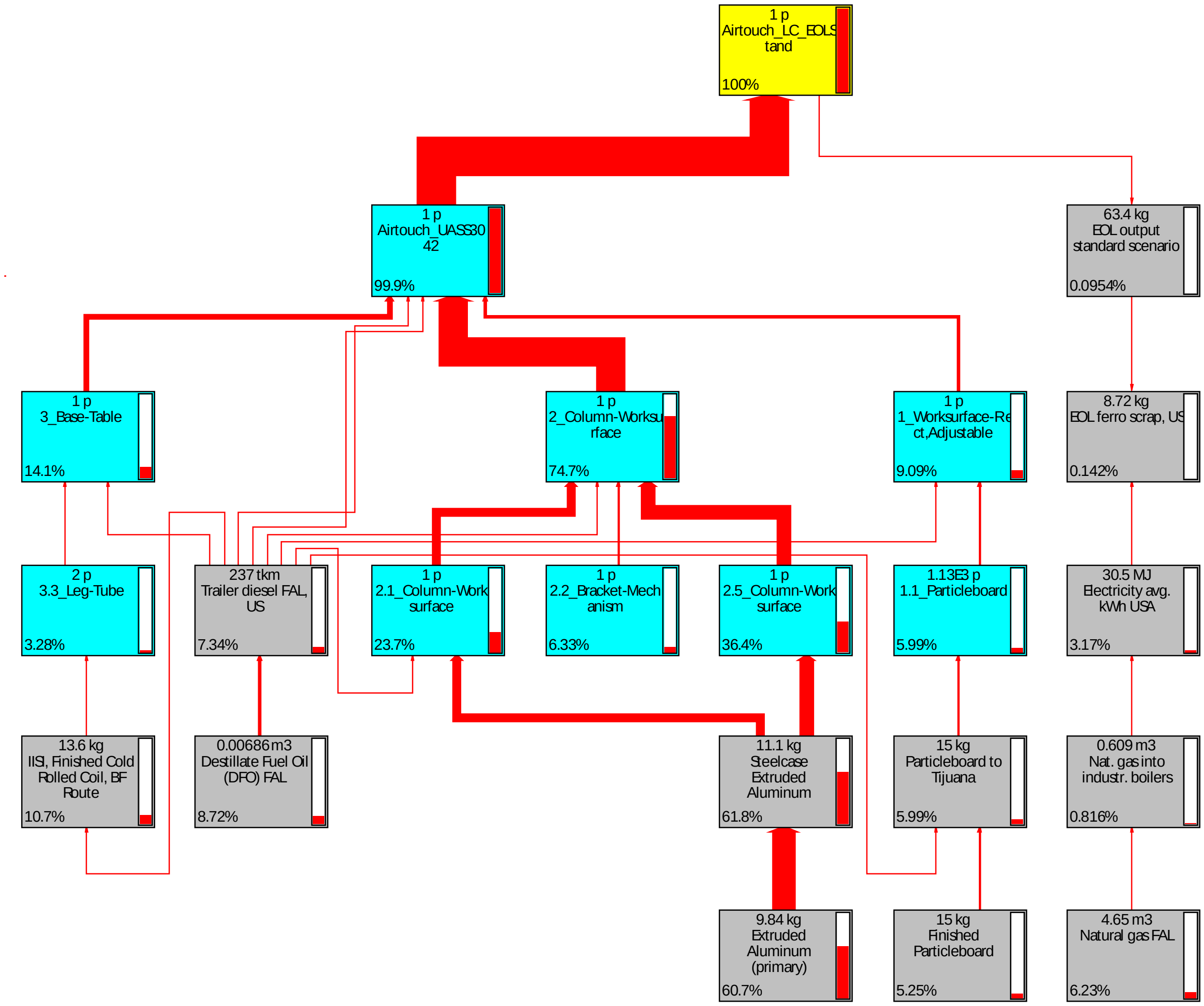

Figure 8: Relative Contribution of Individual Processes to the Overall Life-Cycle Impacts of the AirTouch Product System in the Category of Energy Use

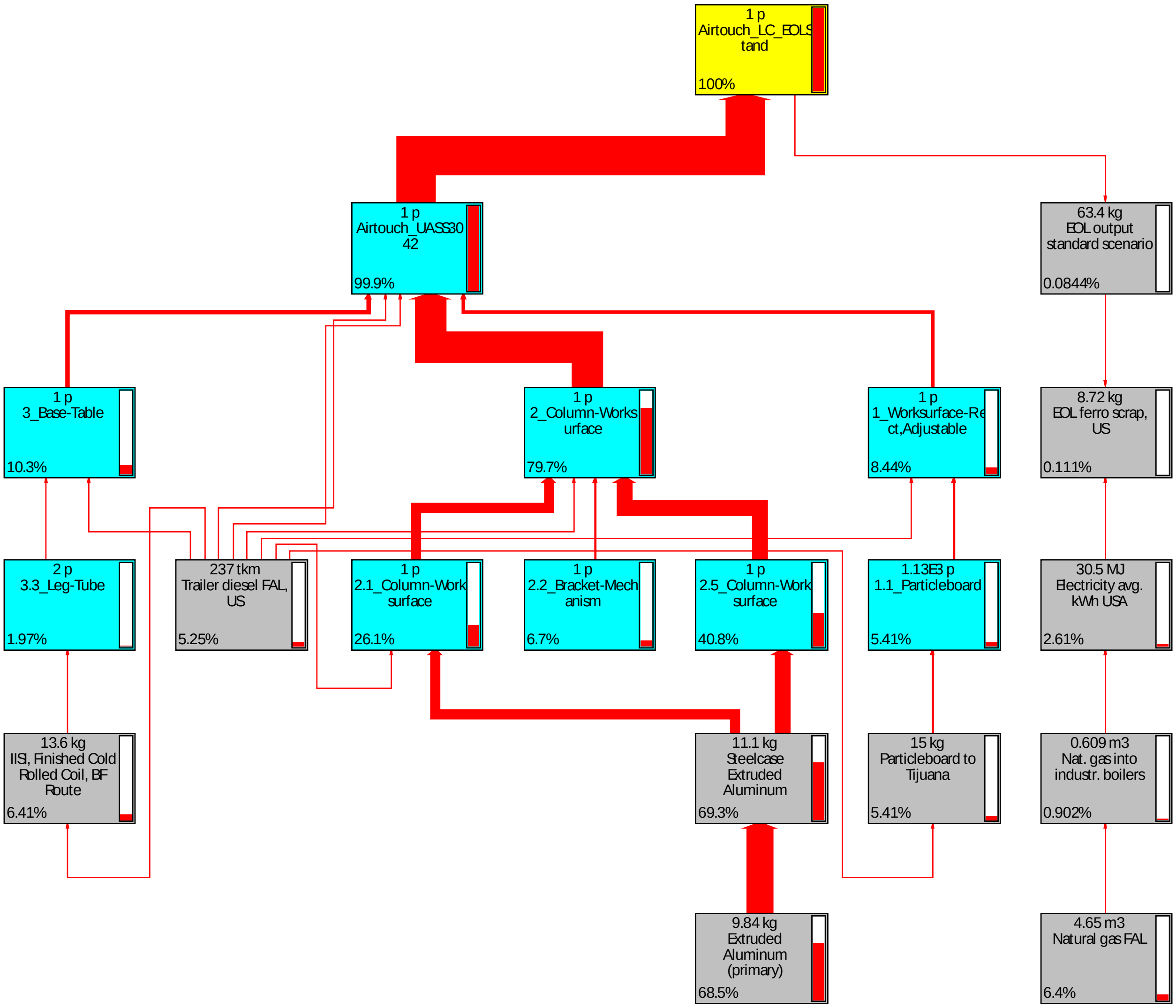

Figure 9: Relative Contribution of Individual Processes to the Overall Life-Cycle Impacts of the AirTouch Product System in the Category of Human Health Criteria

Table 3-6 and Figure 10 provide the overall life-cycle impacts for the AirTouch product system in the six impact categories selected.

Table 3-6: Life-Cycle Environmental Impacts for the AirTouch Product System

Impact Category	Unit	Impact
Energy resource consumption	MJ	3,290
Global warming potential	kg CO_2 eqv.	220
Acidification potential	H^+ mol eqv.	97.5
Criteria pollutants/human health	kg $PM_{2.5}$ eqv.	0.56
Solid waste (excl. recyclables)	kg	79.5
Total material consumption	kg	181

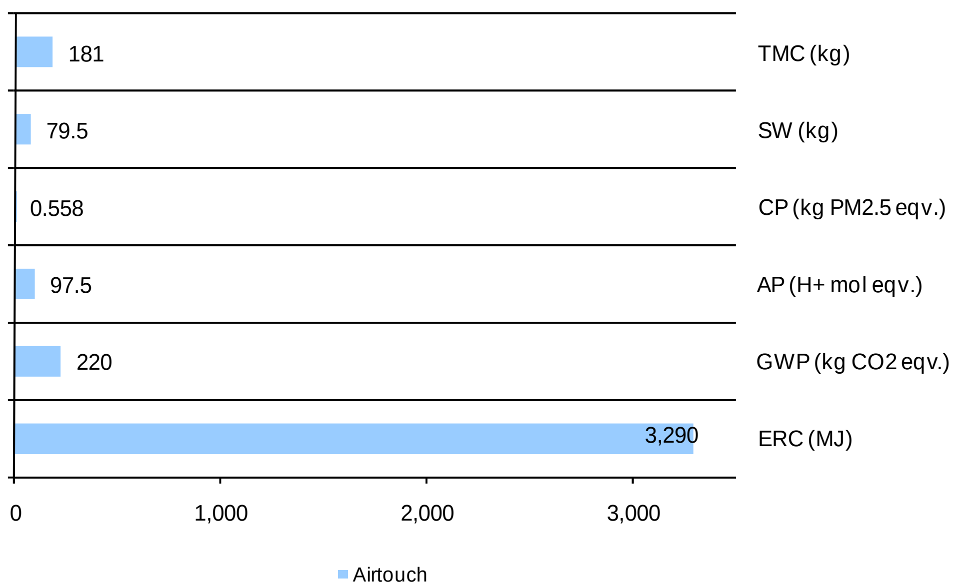

Figure 10: Life-Cycle Environmental Impacts for the AirTouch Product System; TMC = Total Material Consumption;
SW = Solid Waste; CP = Human Health Criteria; AP = Acidification Potential; GWP = Global Warming Potential; ERC = Energy Resource Consumption

3.4. Overall Results and Model Sensitivity

Combined System Performance

Although the product systems studied here each provide a unique function and direct comparison of life-cycle results is meaningless, nevertheless examining results relative to the other product systems does provide some context and supports interpretation of results. Figures 11 and 12 provide the life-cycle impact results for the three product systems side by side. Figure 11 provides the conventional life-cycle results per functional unit of product delivered for each system. Figure 12 provides the life-cycle results normalized per kg of finished product mass. This perspective provides some insights not available in the conventional results, such as an understanding of the relative importance of product mass versus material composition. Consider the relatively massive Garland desk (122 kg), which has the highest energy use on a per functional unit basis of the three products studied. However, on a per kg of product weight basis this product is the least energy intensive of the three. This is largely explained by the importance of wood, with low energy intensity, in the Garland product system.

In addition, the consideration of unrelated product systems may provide useful context for results as well. For example, the life-cycle energy use of these three product systems can be considered in the context of the following values:

- 2964 MJ = primary energy use associated with the operation of a 200 W desktop computer for 1200 hours (30 work weeks) (use only, 2.47 MJ/hr)
- 3000 MJ = primary energy content of ½ barrel of oil
- 3006 MJ = primary energy use associated with driving a car at 27 miles per gallon for 600 miles (use only, 5.01 MJ/mile)

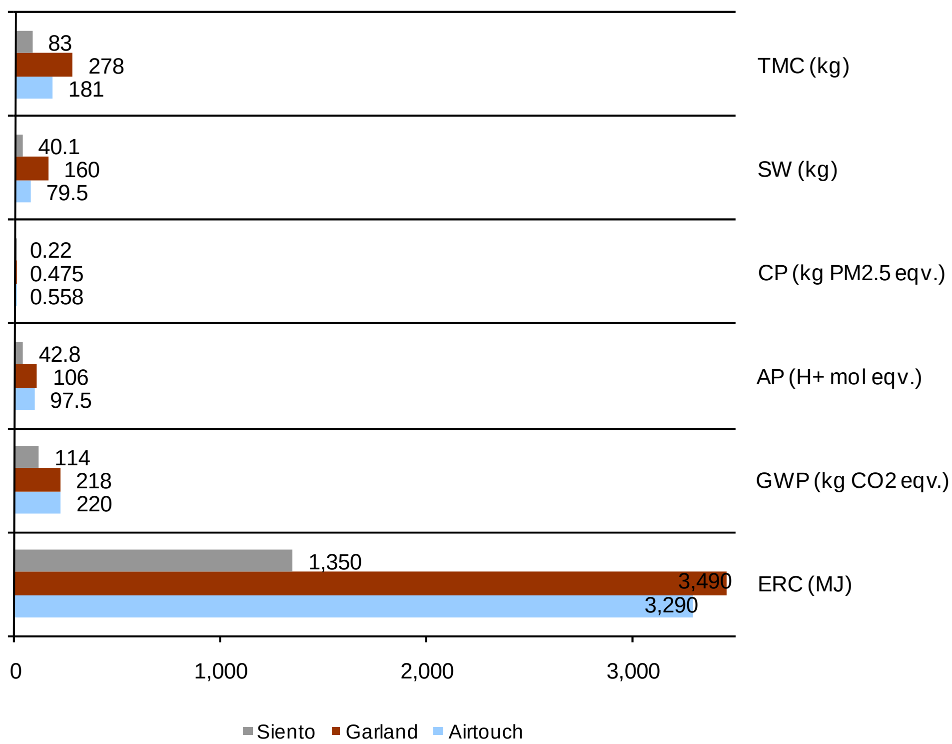

Figure 11: Life-Cycle Environmental Impacts per Functional Unit for the AirTouch, Garland, and Siento Product Systems in Comparison; TMC = Total Material Consumption; SW = Solid Waste; CP = Human Health Criteria; AP = Acidification Potential; GWP = Global Warming Potential; ERC = Energy Resource Consumption

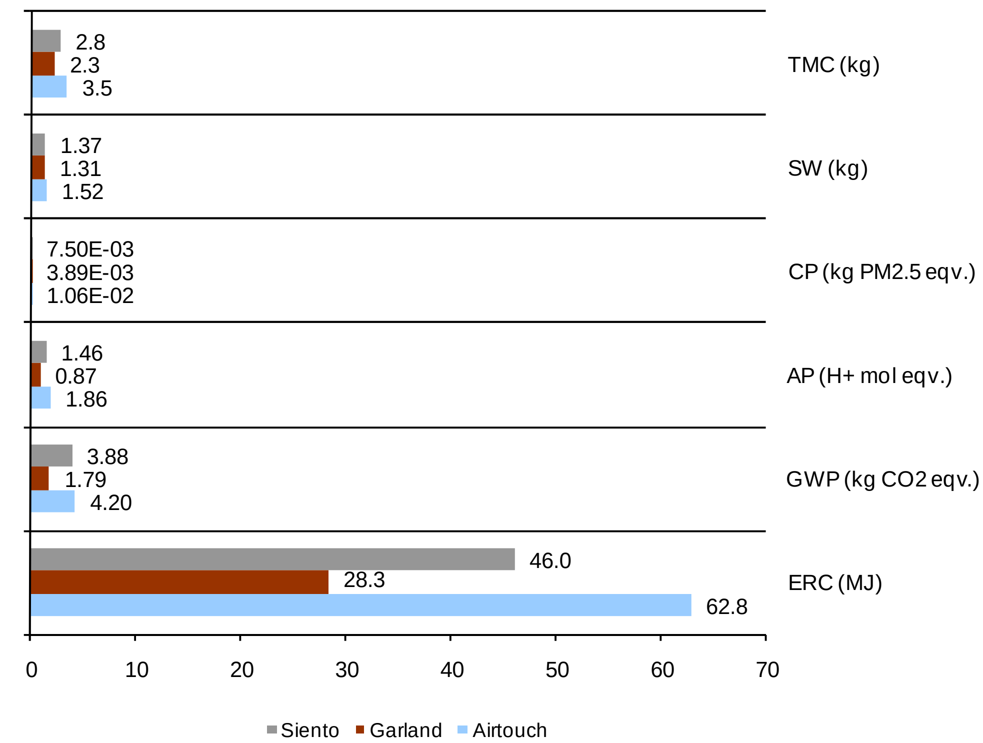

Figure 12: Life-Cycle Environmental Impacts per kg of Finished Product for the AirTouch, Garland, and Siento Product Systems in Comparison; TMC = Total Material Consumption; SW = Solid Waste; CP = Human Health Criteria; AP = Acidification Potential; GWP = Global Warming Potential; ERC = Energy Resource Consumption

Figures 13 and 14 provide additional perspective on the relative performance of each product system. Figure 13 provides the normalized life-cycle performance of each product system per functional unit. Data are normalized based on the maximum value determined in each category.

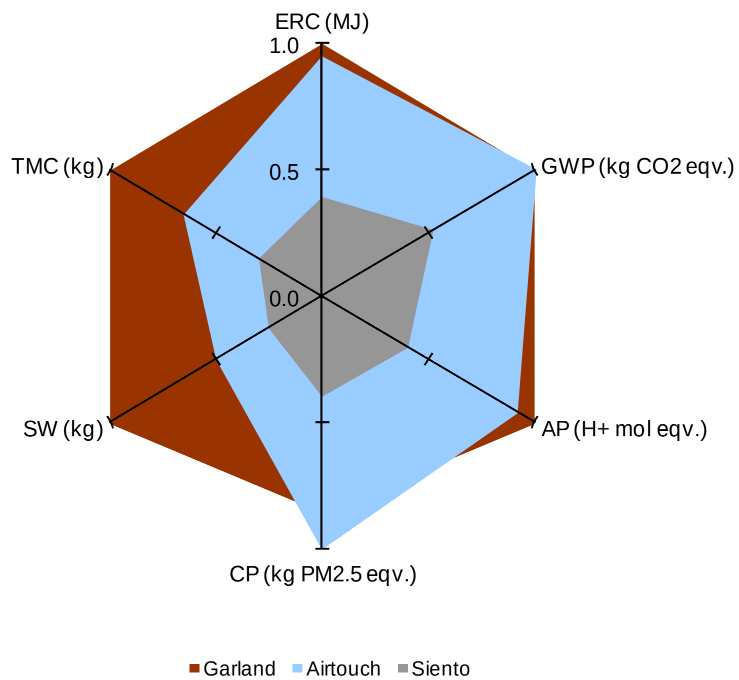

Figure 13: Normalized Life-Cycle Impacts per Functional Unit for the AirTouch, Garland, and Siento Product Systems in Comparison

For example, the life-cycle energy use of the three product systems was determined to be 1370 MJ, 3490 MJ, and 3294 MJ for Siento, Garland and AirTouch respectively. Dividing all values by the maximum (3490 MJ) gives values of 0.4, 1.0, and 0.9. Figure 14 provides the life-cycle results per kg of product mass normalized using the same approach.

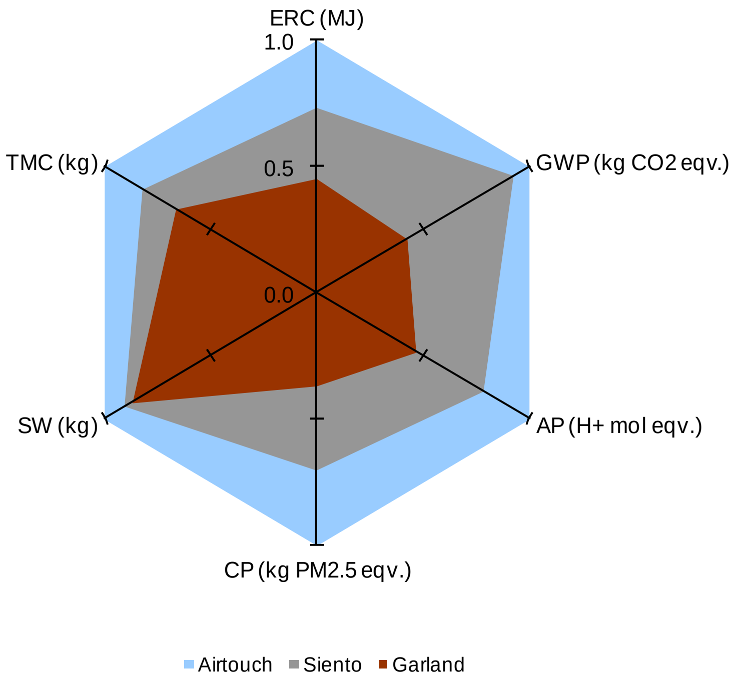

Figure 14: Normalized Life-Cycle Impacts per kg of Finished Product for the AirTouch, Garland, and Siento Product Systems in Comparison

3.5. Sensitivity

Sensitivity of model results to changes in key system parameters and values with a high degree of uncertainty were investigated in a sensitivity analysis.

AirTouch Sensitivity Analysis

Particleboard Resin Content – Particleboard composition was varied to examine the effects of reducing the mass contribution of urea-formaldehyde resin from the current level of 9.5% to 4.9%. Table 3-7 provides the results of this analysis measured in terms of the multiplier effect in each impact category. A multiplier of one would indicate that for every one percent reduction in resin content a one percent reduction in the impact category was observed.

Table 3-7: Life-Cycle Sensitivity Analysis for the AirTouch Product System Concerning the Urea-Formaldehyde Resin Content in Particleboard; Sensitivity is expressed in multiplier factors, that is, the percent reduction for each impact category per every one percent reduction in resin content

Impact Category	Multiplier
ERC (MJ)	0.40
GWP (kg CO_2 eqv.)	0.20
AP (H^+ mol eqv.)	0.58
CP (kg $PM_{2.5}$ eqv.)	0.43
SW (kg)	0.05
TMC (kg)	0.06

Aluminum Extrusion Recycled Content – the contribution of secondary aluminum to the overall composition of products made from extruded aluminum was doubled to examine the effects of recycled content on life-cycle performance. Recycled content in aluminum extrusions was raised from the baseline of 11% to a maximum of 22%. Table 3-8 provides the results of this analysis measured in terms of the multiplier effect in each impact category. A multiplier of one would indicate that for every one percent increase in recycled content a one percent reduction in the impact category was observed.

Table 3-8: Life-Cycle Sensitivity Analysis for the AirTouch Product System Concerning the Recycled Material Content in Extruded Aluminum; Sensitivity is expressed in multiplier factors, that is, the percent reduction for each impact category per every one percent increase in recycled content

Impact Category	Multiplier
ERC (MJ)	0.56
GWP (kg CO_2 eqv.)	0.54
AP (H^+ mol eqv.)	0.62
CP (kg $PM_{2.5}$ eqv.)	0.67
SW (kg)	-
TMC (kg)	0.29

Cast Aluminum Recycled Content – the contribution of secondary aluminum to the overall composition of products made from cast aluminum was increased to examine the effects of recycled content on life-cycle performance. Recycled content in cast parts was raised from the baseline of 85% to a maximum of 99%. Table 3-9 provides the results of this analysis measured in terms of the multiplier effect in each impact category. A multiplier of one would indicate that for every one percent increase in recycled content a one percent reduction in the impact category was observed. The resulting effect is much less dramatic here than with extruded aluminum due to the fact that only 1 kg of cast aluminum is used in the AirTouch product compared to 11 kg of extruded aluminum.

Table 3-9: Life-Cycle Sensitivity Analysis for the AirTouch Product System Concerning the Recycled Material Content in Cast Aluminum; Sensitivity is expressed in multiplier factors, that is, the percent reduction for each impact category per every one percent increase in recycled content

Impact Category	Multiplier
ERC (MJ)	0.02
GWP (kg CO_2 eqv.)	0.03
AP (H^+ mol eqv.)	0.04
CP (kg $PM_{2.5}$ eqv.)	0.05
SW (kg)	-
TMC (kg)	0.03

Garland Sensitivity Analysis

Finish Wood Processing Yield – The overall wood plant material efficiency for the processing of cherry wood (both veneer and nosing) was increased to examine the effects on overall life-cycle performance. Process yield was increased from the baseline value of 30% to a maximum of 45%. Table 3-10 provides the results of this analysis measured in terms of the multiplier effect in each impact category. A multiplier of one would indicate that for every one percent increase in material efficiency a one percent reduction in the impact category was observed.

Table 3-10: Life-Cycle Sensitivity Analysis for the Garland Product System Concerning Finished Wood Processing Yield; Sensitivity is expressed in multiplier factors, that is, the percent reduction for each impact category per every one percent increase in wood processing yield

Impact Category	Multiplier
ERC (MJ)	0.04
GWP (kg CO_2 eqv.)	0.06
AP (H^+ mol eqv.)	0.06
CP (kg $PM_{2.5}$ eqv.)	0.01
SW (kg)	-
TMC (kg)	0.11

Particleboard Resin Content – As was the case in the AirTouch system, particleboard composition was varied to examine the effects of reducing the mass contribution of urea-formaldehyde resin from the current level of 9.5% to a low of 4.9%. Table 3-11 provides the results of this analysis measured in terms of the multiplier effect in each impact category. A multiplier of one would indicate that for every one percent reduction in resin content a one percent reduction in the impact category was observed. The strong influence of this parameter on the system suggests that additional investigations into resin content may be warranted.

Table 3-11: Life-Cycle Sensitivity Analysis for the Garland Product System Concerning the Urea-Formaldehyde Resin Content in Particleboard; Sensitivity is expressed in multiplier factors, that is, the percent reduction for each impact category per every one percent reduction in resin content

Impact Category	Multiplier
ERC (MJ)	2.19
GWP (kg CO_2 eqv.)	1.03
AP (H^+ mol eqv.)	2.70
CP (kg $PM_{2.5}$ eqv.)	2.63
SW (kg)	0.13
TMC (kg)	0.28

Siento Sensitivity Analysis

Leather Processing Yield – The overall leather upholstery process material efficiency for the upholstering of the Siento chair was increased to examine the effects on overall life-cycle performance. Process yield was increased from the baseline value of 60% to a maximum of 90%. Table 3-12 provides the results of this analysis measured in terms of the multiplier effect in each impact category. A multiplier of one would indicate that for every one percent increase in material efficiency a one percent reduction in the impact category was observed.

Table 3-12: Life-Cycle Sensitivity Analysis for the Siento Product System Concerning Leather Processing Yield; Sensitivity is expressed in multiplier factors, that is, the percent reduction for each impact category per every one percent increase in leather processing yield

Impact Category	Multiplier
ERC (MJ)	0.05
GWP (kg CO_2 eqv.)	0.03
AP (H^+ mol eqv.)	0.04
CP (kg $PM_{2.5}$ eqv.)	0.05
SW (kg)	0.09
TMC (kg)	0.00

Cast Aluminum Recycled Content – the contribution of secondary aluminum to the overall composition of products made from cast aluminum was increased to examine the effects of recycled content on life-cycle performance. Recycled content in cast parts was raised from the baseline of 85% to a maximum of 99%. Table 4-12 provides the results of this analysis measured in terms of the multiplier effect in each impact category. A multiplier of one would indicate that for every one percent increase in recycled content a one percent reduction in the impact category was observed.

Table 3-13: Life-Cycle Sensitivity Analysis for the Siento Product System Concerning the Recycled Material Content in Cast Aluminum; Sensitivity is expressed in multiplier factors, that is, the percent reduction for each impact category per every one percent increase in recycled content

Impact Category	Multiplier
ERC (MJ)	0.69
GWP (kg CO_2 eqv.)	0.51
AP (H^+ mol eqv.)	0.67
CP (kg $PM_{2.5}$ eqv.)	0.82
SW (kg)	-
TMC (kg)	0.06

4. Conclusions/Observations

4.1. Comparison with Previous Study

Results are available from the previous CSS life-cycle study of Steelcase products completed in 2005.[5] The previous study provides life-cycle inventory results for a lateral file system, a panel system, and a corner worksurface system. Figures 15 and 16 provide the combined results for the six product systems covered in the two studies. Normalizations shown here are calculated as described in Section 3.4. Care should be taken when comparing studies as the previous analysis involved slightly different methodological and system assumptions and calculated impacts using an older version of the TRACI impact assessment factors. Nevertheless, observations regarding material composition and mass can be made consistently in both systems. For example, the Garland system and the corner worksurface system (from the 2005 study) follow a similar pattern when examined on a per kg basis relative to the other product systems. Both of these systems have substantial material contributions from particleboard.

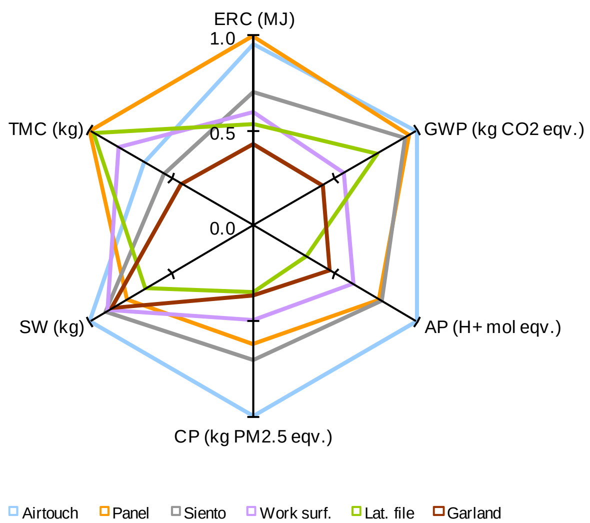

Figure 15: Normalized Life-Cycle Impacts per functional unit for the AirTouch, Garland, and Siento Product Systems as well as the Later File, Panel, and Worksurface Product Systems from the 2005 Study in Comparison

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

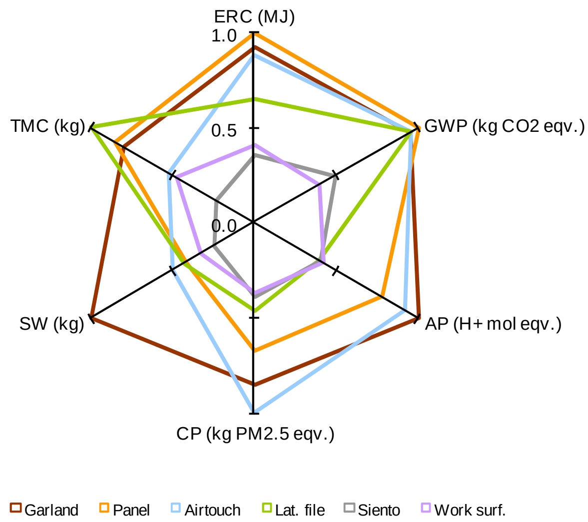

Figure 16: Normalized Life-Cycle Impacts per kg of finished product for the AirTouch, Garland, and Siento Product Systems as well as the Later File, Panel, and Worksurface Product Systems from the 2005 Study in Comparison

4.2. Further Investigations

The life-cycle assessment model developed using the SimaPro tool as part of this project could serve as the basis for examination of similar systems or system alternatives. Steelcase has discussed obtaining a license for the use of SimaPro software; this would enable examination of several alternative scenarios. Examples that have been discussed with Steelcase are noted below.

- Substitution of a metal worksurface for the particleboard worksurface included in the current AirTouch design. This would involve the entry or verification of correct data for the new worksurface materials and adjustments to the data in the assembly product stage '1_Worsurface-Rect, Adjustable' that is part of the AirTouch system.
- Use of a cast aluminum base for the AirTouch table. This would involve verification of the recycled content for cast aluminum from the supplier and adjustment of the data in the assembly product stage '3_Base-Table' in the SimaPro model.
- Development of life-cycle studies for other wood case good products. Data entered into the SimaPro model should be sufficient to support analysis of a wide range of wood case good products with cherry finish.

4.3. Streamlining LCA at Steelcase

Opportunities exist to build on the observations made during this and the previous study to establish streamlined approaches for LCA at Steelcase. These generally involve establishing standard modeling approaches and assumptions. Some examples follow:

- Establish the use of a consistent tool for development of LCA models. Steelcase has discussed the acquisition of SimaPro. The acquisition of a modeling tool would provide consistency in approach and allow multiple studies to easily share data and information.
- Establish a manufacturing process data library. This study has provided information on the electricity use, compressed air usage and cooling water use for 29 types of manufacturing

equipment common in the office furniture industry. Continuing to build a database of manufacturing equipment information will allow calculation of manufacturing burdens based on time required for processing, thus making future studies more efficient. Other, non time based approaches could also be supported using a similar database.

- Establish a consistent approach to the modeling of product delivery impacts. The current analysis calculates an average delivery distance based on rough estimates of expected sales locations. Future studies may integrate more detailed understanding of product distribution or may rely on standard estimates of delivery distance. In either case, using a standard distribution modeling approach should simplify the requirements for subsequent studies.
- Existing data on end of life management practices for office furniture are overly general and likely offer little insight into the actual handling of office furniture waste. Obtaining more accurate end of life management data should be a priority. Future studies should be consistently developed using a standard set of end of life assumptions based on industry knowledge.
- Although product lifetime rarely influences the life-cycle profile of office furniture products, standard assumptions should be made regarding product lifetime. As such, a standard method for determining expected product lifetime should be applied, or alternatively, a single value should be consistently used across all studies.

4.4. Observations on LCA at Steelcase

Steelcase faces a challenge common to many original equipment manufacturers, that is, a lack of cooperation and information from suppliers. In these situations, life-cycle studies need to be carefully designed to rely on available (either public or private) databases as sources of material and process information. In many cases, suppliers or other external organizations may hold key data not otherwise available. Obtaining supplier cooperation prior to study initiation may help, however, in many cases sensitivity analysis may be required to understand the uncertainty introduced by lack of specific data.

The conduct of a full ISO-type LCA requires specific information on product composition, manufacturing process, use and disposal. Frequently, this information has not been determined early in the design process. Nevertheless, LCA can support the consideration of fully designed and planned products or the consideration of well defined design alternatives. In addition, simplified versions of LCA, such as so called ‘cradle to gate’ material data together with rough product composition can be used effectively in the design process to guide decisions.

Steelcase continues to make significant progress in identifying new opportunities to reduce environmental impacts in both their products and facilities. The judicious use of life-cycle assessment will serve to further this goal while providing a scientifically sound, defensible basis for development of environmental product declaring. Hopefully, LCA will continue to bridge the design, engineering and marketing communities leading to products that inspire customers while reducing environmental impacts.

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Appendices

Appendix A

Siento: Bill of Materials Used in Life-Cycle Modeling

Tree	Part Description	Material Composition	Manufacturing Process	Part (lb)	Qty.	Tot. (lb)
1.1	Casters - hard (Chrome)				1	
1.1.1	Body - 20mm Neck	Zinc I, US	Cast work, non-ferro, US	0.2100	5	1.0500
1.1.2	Caster Wheels	Nylon 6	Injection molding, US	0.3100	5	1.5500
1.1.3	Pintle	IISI, Eng. Steel, EAF Route	Cold transform. steel, US	0.0770	5	0.3850
1.2	Base, Polished	Steelcase Cast Aluminum	Incl. in material model	6.0010	1	6.0010
1.3	Pneumatic Cylinder	IISI, Eng. Steel, EAF Route	Machining steel, US	2.3000	1	2.3000
2.1	Chair Control – assym.				1	0.0000
2.1.1	Pneu Handle Anti-Rattle Pad				1	0.0000
2.1.2	Pneu Handle Anti-Rattle				1	0.0000
2.1.3	Pneu Handle Anti-Click Pad				1	0.0000
2.1.4	Pneu Knob			0.0210	1	0.0210
2.1.5	Pneu Lever	IISI, Rebar, EAF Route	Cold transform. steel, US	0.2620	1	0.2620
2.1.6	Pneu Adjuster			0.0110	1	0.0110
2.1.7	Pneu Adjuster screw				1	0.0000
2.1.8	Torque Adj Knob	Nylon 6	Injection molding, US	0.0968	1	0.0968
2.1.9	Torque rod sleeve				1	0.0000
2.1.10	Back Lock Knob			0.0210	1	0.0210
2.1.11	Back Lock Lever	IISI, Rebar, EAF Route	Cold transform. steel, US	0.2780	1	0.2780
2.1.12	Back Lock	Nylon 6/6 / Glass Fiber Comp.	Injection molding, US	0.0860	1	0.0860
2.1.13	Back Lock Lever Retainer			0.0010	1	0.0010
2.1.14	Weldment - Seat Mount				1	
2.1.14.1	Seat Pivot Bracket	GS-10Ni6 I	Incl. in material model	1.3310	1	1.3310
2.1.14.2	Bracket, Arm Pivot	GS-10Ni6 I	Incl. in material model	0.2330	1	0.2330
2.1.14.3	Bearing - Fixed, Front			0.0250	1	0.0250
2.1.15	Bearing - Seat Mount, Front			0.0170	1	0.0170
2.1.16	Bearing - Seat Mount, Rear			0.0170	2	0.0340
2.1.17	Pivot Pin - Seat Mount				2	0.0000
2.1.18	Retainer- Pivot Pin			0.0020	2	0.0040
2.2	STRAP ASSEMBLY - FRONT				1	
2.2.1	ARM STRAP - FRONT	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	1.7840	1	1.7840
2.2.2	PAD - SLIDE, FRONT, LH			0.0157	1	0.0157
2.2.3	PAD - SLIDE, FRONT, RH			0.0157	1	0.0157
2.2.4	SPRING - SEAT TILT	Glass, fiber- or -wool, US		0.0513	1	0.0513
2.3	Rear arm strap weldment				1	
2.3.1	Support Plate, Rear arm strap	IISI, F. Cold Roll. Coil, BF Route	Cutting steel laser, US	0.0960	2	0.1920
2.3.2	ARM STRAP ASSEMBLY				1	0.0000
2.3.2.1	PAD, REAR SLIDE - RH			0.0195	1	0.0195
2.3.2.2	PAD, REAR SLIDE - LH			0.0195	1	0.0195
2.3.2.3	RIVET - SHOULDER, FLAT HEAD			0.0181	2	0.0362
2.3.2.4	STRAP - ARM, TYPE 2	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	1.7840	1	1.7840
2.4	POWER PACK ASSEMBLY				1	

3.1	HOUSING ASSEMBLY				1	
3.1.1	HOUSING - CONTROL, CHAIR	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	1.8100	1	1.8100
3.1.2	SUPPORT BUSHING, 28MM	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	0.6610	1	0.6610
3.1.3	BUSHING - HOUSING TAPERED	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	0.1340	1	0.1340
3.1.4	FILLER - WELD, WIRE, STEEL			0.0000	1	0.0000
3.2	SUPPORT ASSEMBLY – UPR.				1	
3.2.1	SUPPORT - UPRIGHT	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	2.7570	1	2.7570
3.2.2	SUPPORT - PIVOT SYNCHRO	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	0.0840	2	0.1680
3.3	SLEEVE - AXLE			0.0390	1	0.0390
3.4	TUBE - AXLE	IISI, Steel Section, EAF Route	Machining steel, US	0.4610	1	0.4610
3.5	SPRING - TORSION, LEFT HAND	IISI, Rebar, EAF Route	Cold transform. steel, US	0.9200	1	0.9200
3.6	SPRING - TORSION, RIGHT	IISI, Rebar, EAF Route	Cold transform. steel, US	0.9200	1	0.9200
3.7	BRACKET - SPRING, TENSION	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	0.2630	1	0.2630
3.8	SHAFT - ADJUSTMENT, TEN.	IISI, F. Cold Roll. Coil, BF Route	Machining steel, US	0.3280	1	0.3280
3.9	NUT - ADJUSTMENT, TENSION	IISI, Eng. Steel, EAF Route		0.0480	1	0.0480
3.10	PLATE - PIVOT TENSION	IISI, F. Cold Roll. Coil, BF Route	Mech. press, SC avg.	0.3170	1	0.3170
3.11	BUTTON - STOP			0.0030	2	0.0060
3.12	BEARING - AXLE			0.0090	2	0.0180
3.13	GREASE - MULTI-PURPOSE			0.0000	0	0.0000
3.14	BUSHING - BRONZE			0.0010	1	0.0010
3.15	RIVET - PIVOT TENSION			0.0240	1	0.0240
3.16	WASHER - PLAIN,NON-STD			0.0030	2	0.0060
3.17	WASHER - NON STANDARD			0.0010	1	0.0010
4.1	Shell, Inner Seat	PP Injection Molding	Incl. in material model	3.0100	1	3.0100
4.1.1	T-Nut for seat inner			0.0010	4	0.0040
4.2	Shell, Outer seat	PP Injection Molding	Incl. in material model	0.8480	1	0.8480
4.3	Screws - outer Seat attachment			0.0010	5	0.0050
4.4	Foam, Topper, Seat	Polyurethane Flexible Foam	Incl. in material model	0.2200	1	0.2200
4.5	Foam, Molded - Seat	Polyurethane Flexible Foam	Incl. in material model	2.0280	1	2.0280
4.6	Upholstery - Seat	Leather I, US	Hand tool	0.7940	1	0.7940
5.1	T Arm, LH, Polished	Steelcase Cast Aluminum	Incl. in material model	2.8720	1	2.8720
5.2	T Arm, RH, Polished	Steelcase Cast Aluminum	Incl. in material model	2.8720	1	2.8720
5.3	Screws - T Arm Cap Attachment				8	0.0000
5.4	Upholstery - T Arm Cap	Leather I, US	Hand tool	0.1000	2	0.2000
5.6	T Arm Cap - Molded	Polyurethane Flexible Foam	Incl. in material model	0.0440	2	0.0880
5.6.1	T Arm Cap inner	PP Injection Molding	Incl. in material model	0.1320	2	0.2640
5.7	Screw - Arm Attachment				6	0.0000
6.1	Back Assembly - High				1	
6.1.1	Back Mechanism - High				1	
6.1.1.1	Weldment - Back Attachment				1	
6.1.1.2	Tube, Back Mounting	IISI, Steel Section, EAF Route	Cutting steel laser, US	0.3600	2	0.7200
6.1.1.3	Tube, Cross Stretcher	IISI, Steel Section, EAF	Cold transform. steel, US	1.8370	1	1.8370

		Route				
6.1.1.4	Link, Lower Inner, RH	GS-10Ni6 I	Incl. in material model	0.2780	1	0.2780
6.1.1.5	Link, Lower Inner, LH	GS-10Ni6 I	Incl. in material model	0.2780	1	0.2780
6.1.1.6	Link, Lower Outer	GS-10Ni6 I	Incl. in material model	0.4850	2	0.9700
6.1.2	Weldment - Link, Inner				1	
6.1.2.1	Link, Inner, RH	GS-10Ni6 I	Incl. in material model	1.3010	1	1.3010
6.1.2.2	Link, Inner, LH	GS-10Ni6 I	Incl. in material model	1.3010	1	1.3010
6.1.2.3	Cross Member - Middle	IISI, Rebar, EAF Route	Cold transform. steel, US	0.3720	1	0.3720
6.1.2.4	Cross Member - Lower	IISI, Rebar, EAF Route	Cold transform. steel, US	0.3910	1	0.3910
6.1.2.5	Flange - Inner Link, RH	GS-10Ni6 I	Incl. in material model	0.4550	1	0.4550
6.1.2.6	Flange - Inner Link, LH	GS-10Ni6 I	Incl. in material model	0.4550	1	0.4550
6.1.3	Weldment - Link, Upper				1	
6.1.3.1	Cross Member, Upper	IISI, Rebar, EAF Route	Cold transform. steel, US	0.4040	1	0.4040
6.1.3.2	Bracket - Belt Attachment			0.0130	3	0.0390
6.1.3.3	Back Wire	IISI, Rebar, EAF Route	Cold transform. steel, US	2.6340	1	2.6340
6.1.3.4	Link, Upper, Inner, RH	GS-10Ni6 I	Incl. in material model	0.1320	1	0.1320
6.1.3.5	Link, Upper, Inner, LH	GS-10Ni6 I	Incl. in material model	0.1350	1	0.1350
6.1.3.7	Link, Upper, Outer	IISI, F. Cold Roll. Coil, BF Route	Cutting steel laser, US	0.1890	2	0.3780
6.1.3.8	Bracket, Inner Back	GS-10Ni6 I	Incl. in material model	0.3090	2	0.6180
6.1.4	Bushing, Main			0.0060	6	0.0360
6.1.5	Bushing, Lower			0.0020	2	0.0040
6.1.6	Washer, Pivot			0.0010	8	0.0080
6.1.7	Rivet, Main	IISI, Eng. Steel, EAF Route	Cold transform. steel, US	0.0400	6	0.2400
6.1.8	Rivet, Lower			0.0200	2	0.0400
6.1.9	Spring	IISI, Rebar, EAF Route	Cold transform. steel, US	0.1330	2	0.2660
6.1.10	Bearing, Spring			0.0100	4	0.0400
6.1.11	Bumper Stop			0.0020	4	0.0080
6.1.12	Link, Outer, RH	GS-10Ni6 I	Incl. in material model	0.6150	1	0.6150
6.1.13	Link, Outer, LH	GS-10Ni6 I	Incl. in material model	0.6150	1	0.6150
6.1.14	Bracket, Inner Back	GS-10Ni6 I	Incl. in material model	0.3090	2	0.6180
6.2	Shield - Lower Link			0.0110	2	0.0220
6.3	Upper Back assembly				1	0.0000
6.3.1	Upper back	PNW Softwood Plywood	Incl. in material model	1.4270	1	1.4270
6.3.2	T-nuts, 1/4-20, pronged			0.0075	4	0.0298
6.4	Screws - Upper back attachm.				4	0.0000
6.5	Staple Strip	PNW Softwood Plywood	Incl. in material model	0.2110	1	0.2110
6.6	Screw - Staple Strip retaining				2	0.0000
7.1	Dimatrol Assembly				1	
7.1.1	Dimatrol	Polyester fabric I, US	Incl. in material model	0.2500	1	0.2500
7.1.2	D ring			0.0030	2	0.0060
7.1.3	Channel, Side, RH	PP Injection Molding	Incl. in material model	0.1470	1	0.1470
7.1.4	Channel, Side, LH	PP Injection Molding	Incl. in material model	0.1470	1	0.1470
7.1.5	Extrusion, J, Top	PP Injection Molding	Incl. in material model	0.0680	1	0.0680
7.1.6	Extrusion, J	PP Injection Molding	Incl. in material model	0.0680	3	0.2040
7.2	Upholstery, High Back	Leather I, US	Hand tool	1.3670	1	1.3670
7.3	Foam, Topper, High Back	Polyurethane Flexible Foam	Incl. in material model	0.1320	1	0.1320
7.4	Foam, High Back, Front	Polyurethane Flexible Foam	Incl. in material model	1.5210	1	1.5210
7.5	Foam, High Back, Rear	Polyurethane Flexible Foam	Incl. in material model	1.5210	1	1.5210
8.1	Belt, Inner	PP Injection Molding	Incl. in material model	0.3070	1	0.3070
8.2	Pop Rivet - 1/8"				10	0.0000
8.3	Belt, Outer	PP Injection Molding	Incl. in material model	0.1790	1	0.1790
8.4	Screw - Outer Belt Retaining				4	0.0000
8.5	Shell, Back - Upholstered				1	0.0000

8.5.1	Shell, Back	PP Injection Molding	Incl. in material model	1.9160	1	1.9160
8.5.2	Guide, Belt	Nylon 6	Injection molding, US	0.0550	1	0.0550
8.5.3	Screw, belt guide attachment				2	0.0000
8.5.4	Foam - Back Shell			0.0440	1	0.0440
8.5.5	Upholstery, Back Shell	Leather I, US	Hand tool	0.2500	1	0.2500
8.5.6	Fastener - Christmas Tree				4	0.0000
8.6	SCREW - TAPPING,TRUSS					0.0000

Appendix B

AirTouch: Bill of Materials Used in Life-Cycle Modeling

Tree	Part Description	Material Composition	Part (lb)	Qty.	Tot. (lb)
1.1	PARTICLEBOARD	Particleboard	0.0293	1130	33.1090
1.2	LAMINATE	Laminate	0.0014	1130	1.5368
1.3	SHEET - BACKUP	Backer laminate	0.0015	1130	1.6498
1.4	EDGE - WORKSURFACE	PVC (extruded)	0.0020	97	0.1940
1.5	EDGE - WORKSURFACE	PVC (extruded)	0.0070	40	0.2800
1.6	ADHESIVE - HOT MELT		0.1000	0.0417	0.0042
1.7	ADHESIVE - PRESSURE SENS.	Ethylene (as surrogate)	0.5000	0.3688	0.1844
1.8	LABEL - PATENT		0.0010	1	0.0010
1.9.1	LABEL - BLANK		0.0284	1	0.0284
1.9.2	INK		1.1900	0.00035	0.0004
1.10	ASSEMBLY DIRECTION		0.0800	1	0.0800
1.11	ADHESIVE - HOT MELT		0.1000	0.0417	0.0042
1.12	ADHESIVE - PRESSURE SENS.	Ethylene (as surrogate)	0.5800	0.3688	0.2139
1.13.1	LABEL - BLANK		0.0001	1	0.0001
1.13.2	INK		1.1900	0.00014	0.0002
1.14	ADHESIVE - HOT MELT		0.0000	0.0417	0.0000
2.1	COLUMN - WORKSURFACE	Extruded Aluminum, 11% sec.	8.8714	1	8.8714
2.2.1	PLATE - MOUNTING	Cast Aluminum, 85% sec.	0.9776	1	0.9776
2.2.2	PIN - PIVOT		0.0480	1	0.0480
2.2.3	CAM	Cast Aluminum, 85% sec.	0.6493	1	0.6493
2.2.4	BALL - BEARING		0.0390	2	0.0780
2.2.5	SPRING - COMPRESSION	50CrV4 Steel	2.1785	1	2.1785
2.2.6	SCREW - TAPPING		0.0070	4	0.0280
2.2.7	GUIDE	Extruded Aluminum, 11% sec.	0.5745	2	1.1490
2.2.8	BEARING	HDPE Resin	0.0286	8	0.2291
2.2.9	BRACKET	Rolled Aluminum, 7% sec.	0.3120	1	0.3120
2.2.10	MOUNT - VIBRATION		0.0020	6	0.0120
2.2.11	NUT - ACORN	304 Stainless Steel	0.1140	3	0.3420
2.2.12.1.1	NUT - SPECIAL		0.0190	1	0.0190
2.2.12.1.2	NUT - SPECIAL		0.0135	1	0.0135
2.2.12.2	BRAKE - ACTUATOR	Cast Iron (as surrogate)	0.0651	4	0.2604
2.2.12.3	SPRING - EXTENSION		0.0098	1	0.0098
2.2.12.4	CAP - FILLER		0.0110	1	0.0110
2.2.12.5	HOUSING - CONNECTOR		0.0472	1	0.0472
2.2.12.6	BEARING - THRUST	Steel, Finished Cold Roll. Coil	0.0820	2	0.1640
2.2.12.7	HOUSING - CONNECTOR		0.0809	1	0.0809
2.2.12.8	SCREW - SPECIAL	Steel, screw, self tapping	0.5623	1	0.5623
2.2.12.9	GROMMET		0.0016	1	0.0016
2.2.12.10	PLATE - MOUNTING		0.0558	1	0.0558
2.2.12.11	SPRING - COMPRESSION		0.0180	1	0.0180
2.2.12.12	WASHER - WAVE		0.0010	2	0.0020
2.2.12.13	BUSHING		0.0021	2	0.0041
2.2.12.14	PLATE - MOUNTING		0.1044	1	0.1044
2.2.12.15	HANDLE	304 Stainless Steel (surrogate)	0.2144	1	0.2144
2.2.12.16	BRAKE - ACTUATOR	Cast Iron (surrogate)	0.2832	1	0.2832

2.2.12.17	CABLE PACKAGE	Steel, Cold Roll. Coil	0.1530	1	0.1530
2.2.12.18	WASHER - SPECIAL		0.0050	1	0.0050
2.2.12.19	PIN - SPRING		0.0014	1	0.0014
2.2.13	PLATE - MOUNTING	Steel, Hot Dipped Galvanized	0.1590	1	0.1590
2.2.14	CLIP		0.0010	2	0.0020
2.2.15	SPACER		0.0010	2	0.0020
2.2.16	SCREW - TAPPING		0.0060	4	0.0240
2.2.17	CABLE - POWER	Rebar/Wire	0.8854	1	0.8854
2.2.18	LABEL - WARNING		0.0001	1	0.0001
2.3.1	BALL - BEARING	Engineering Steel	0.0390	8	0.3120
2.3.2	SPACER		0.0025	8	0.0202
2.3.3	SCREW - SPECIAL	Steel, screw, self tapping	0.0169	8	0.1351
2.4	PLATE - MOUNTING	Steel, Finished Cold Roll. Coil	5.8044	1	5.8044
2.5	COLUMN - WORKSURFACE	Extruded Aluminum, 11% sec.	14.3620	1	14.3620
2.6	RETAINER		0.1218	1	0.1218
2.7	RETAINER	Steel, Hot Dipped Galvanized	0.1415	1	0.1415
2.8	CAP - JUNCTION		0.0935	1	0.0935
2.9	RAIL	Engineering Steel	0.0760	8	0.6080
2.10	PAD		0.0026	2	0.0053
2.11	PAD		0.0020	4	0.0080
2.12	PLATE - MOUNTING	Steel, Finished Cold Roll. Coil	6.0549	1	6.0549
2.13	ASSEMBLY DIRECTION		0.0800	1	0.0800
2.14	LABEL - PATENT		0.0001	1	0.0001
2.15	LABEL - CAUTION		0.0001	1	0.0001
2.16	LABEL - WARNING		0.0001	1	0.0001
2.17	LABEL - NOTICE		0.0001	1	0.0001
2.18	SCREW - TAPPING		0.0030	6	0.0180
3.1	PLATE - CURVED	Steel, Finished Cold Roll. Coil	8.9609	1	8.9609
3.2	TUBE - SQUARE	Steel, Cold Formed Section	6.9782	2	13.9563
3.3	LEG - TUBE	IISI, Steel Section, EAF Route	4.6130	2	9.2260
3.3	GLIDE		0.0010	4	0.0040
3.4	CAP - END	Steelcase Cast Aluminum	0.1720	4	0.6880

Appendix C

Garland: Bill of Materials Used in Life-Cycle Modeling

Tree	Part Name	Material Modeled	Part (lb)	Qty.	Tot. (lb)
4	WORKSURFACE – RECTANG.	95.8% PB, 2.1% B, 1.2% CV, 0.6% A, 0.4% F [6]	76.2716	1	76.2716
4.1	NOSING	Cherry Wood	2.1240	2	4.2480
10	ANGLE	IISI, Finished Cold Roll. Coil, BF Route	1.2580	1	1.2580
11	SCREW - TAPPING	Screw, self-tapping	0.0100	10	0.1000
12	SCREW - TAPPING	Screw, self-tapping	0.0100	12	0.1200
13	CLEAT - ATTACHMENT	Poplar I, US	0.4417	2	0.8833
14	PIN - DOWEL	Red oak I, US	0.1000	10	1.0000
15	FILE - PEDESTAL	Assembly	83.4740	1	0.0000
15.1	HEADSET - DRAWER	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	6.1470	1	6.1470
15.2	FILE BACK	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	6.2830	1	6.2830
15.3	BASE - WOOD	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	1.6100	1	1.6100
15.4	SUPPORT - WKSF, END	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	15.0100	1	15.0100
15.5	PANEL - KNEE	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	16.3556	1	16.3556
15.6	ANGLE	IISI, Finished Cold Roll. Coil, BF Route	1.2580	2	2.5160
15.7	ANGLE	IISI, Hot-dip Galvanized Coil, BF Route	0.4500	2	0.9000
15.8	LOCK - CATCH	IISI, Finished Cold Roll. Coil, BF Route	0.0190	2	0.0380
15.9	STRETCHER - RAIL	IISI, Finished Cold Roll. Coil, BF Route	1.0000	1	1.0000
15.1	BRACKET	IISI, Engineering Steel, EAF Route	0.3820	4	1.5280
15.11	HARDWARE PACKAGE		1.0000	2	0.0000
15.11.1	HANDLE	IISI, Finished Cold Roll. Coil, BF Route	0.1520	2	0.3040
15.11.2	SCREW - MACHINE	IISI, Engineering Steel, EAF Route	0.0100	4	0.0400
15.12	GLIDE		0.0090	4	0.0360
15.13	COVER - LOCK	IISI, Finished Cold Roll. Coil, BF Route	0.0230	1	0.0230
15.14	BUMPER	Polyurethane	0.0500	4	0.2000
15.15	SCREW - TAPPING	Screw, self-tapping	0.0100	8	0.0800
15.16	FILE HANGER	PVC (extruded)	0.0450	4	0.1800
15.17	SCREW - TAPPING	Screw, self-tapping	0.0100	2	0.0200
15.18	SCREW - TAPPING	Screw, self-tapping	0.1000	16	1.6000
15.19	SCREW - TAPPING	Screw, self-tapping	0.0100	60	0.6000
15.2	LOCK - HOUSING	ZnCuTi I, US	0.1130	1	0.1130
15.21	LOCK - PLUG	ABS	0.0050	1	0.0050
15.22	FILE HANGER	PVC (extruded)	0.0260	4	0.1040
15.23	LOCK - BAR	IISI, Finished Cold Roll. Coil, BF Route	0.4859	1	0.4859
15.24	SLIDE	IISI, Finished Cold Roll. Coil, BF Route	2.9800	2	5.9600
15.25	SLIDE	IISI, Finished Cold Roll. Coil, BF Route	2.9800	2	5.9600
15.26	DRAWER - FILE	Assembly	8.4430	2	0.0000
15.26.1	GUIDE - DRAWER TRACK	IISI, Finished Cold Roll. Coil, BF Route	0.2100	2	0.4200
15.26.2	GUIDE - DRAWER TRACK	IISI, Finished Cold Roll. Coil, BF Route	0.2100	2	0.4200
15.26.3	SCREW - TAPPING	Screw, self-tapping	0.1000	16	1.6000

[6] PB = Particleboard, B = Backer, CV = Cherry Veneer, A = Adhesive, F = Finish

15.26.4	Purchased plywood Drawer	plywood CORIM data	7.2230	2	14.4460
15.27	PIN - DOWEL	Red oak I, US	0.1000	4	0.4000
15.28	HARDWARE PACKAGE		0.9940	1	0.0000
15.28.1	RAIL	IISI, Finished Cold Roll. Coil, BF Route	0.4970	2	0.9940
17	FILE - PEDESTAL	Assembly	82.8640	1	0.0000
17.1	HEADSET - DRAWER	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	6.1470	1	6.1470
17.2	FILE BACK	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	6.2830	1	6.2830
17.3	BASE - WOOD	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	1.6100	1	1.6100
17.4	SUPPORT - WKSF, END	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	15.0100	1	15.0100
17.5	PANEL - KNEE	95.0% PB, 3.8% CV, 0.9% A, 0.4% F	16.3556	1	16.3556
17.6	ANGLE	IISI, Finished Cold Roll. Coil, BF Route	1.2580	2	2.5160
17.7	ANGLE	IISI, Hot-dip Galvanized Coil, BF Route	0.4500	2	0.9000
17.8	LOCK - CATCH	IISI, Finished Cold Roll. Coil, BF Route	0.0190	3	0.0570
17.9	STRETCHER - RAIL	IISI, Finished Cold Roll. Coil, BF Route	0.9930	1	0.9930
17.1	HARDWARE PACKAGE	Assembly	0.1510	3	0.0000
17.10.1	HANDLE	IISI, Finished Cold Roll. Coil, BF Route	0.1520	3	0.4560
17.10.2	SCREW - MACHINE	IISI, Engineering Steel, EAF Route	0.0100	6	0.0600
17.11	BRACKET	IISI, Engineering Steel, EAF Route	0.3820	4	1.5280
17.12	GLIDE		0.0090	4	0.0360
17.13	SCREW - TAPPING	Screw, self-tapping	0.0100	60	0.6000
17.14	COVER - LOCK	IISI, Finished Cold Roll. Coil, BF Route	0.0230	1	0.0230
17.15	BUMPER	Polyurethane	0.0500	6	0.3000
17.16	SCREW - TAPPING	Screw, self-tapping	0.0100	2	0.0200
17.17	FILE HANGER	PVC (extruded)	0.0450	2	0.0900
17.18	SCREW - TAPPING	Screw, self-tapping	0.0100	12	0.1200
17.19	SCREW - TAPPING	Screw, self-tapping	0.1000	20	2.0000
17.2	LOCK - HOUSING	ZnCuTi I, US	0.1130	1	0.1130
17.21	LOCK - PLUG	ABS	0.0050	1	0.0050
17.22	FILE HANGER	PVC (extruded)	0.0260	2	0.0520
17.23	LOCK - BAR	IISI, Finished Cold Roll. Coil, BF Route	0.4860	1	0.4860
17.24	SLIDE	IISI, Finished Cold Roll. Coil, BF Route	2.9800	1	2.9800
17.25	SLIDE	IISI, Finished Cold Roll. Coil, BF Route	2.9800	1	2.9800
17.26	GUIDE - DRAWER TRACK	IISI, Finished Cold Roll. Coil, BF Route	1.1900	4	4.7600
17.27	DRAWER - BOX	Assembly	6.8720	2	0.0000
17.27.1	GUIDE - DRAWER TRACK	IISI, Finished Cold Roll. Coil, BF Route	0.2100	2	0.4200
17.27.2	GUIDE - DRAWER TRACK	IISI, Finished Cold Roll. Coil, BF Route	0.2100	2	0.4200
17.27.3	SCREW - TAPPING	Screw, self-tapping	0.1000	16	1.6000
17.27.4	Purchased plywood Drawer	plywood CORIM data	5.6520	2	11.3040
17.28	DRAWER - FILE	Assembly	8.4430	1	0.0000
17.28.1	GUIDE - DRAWER TRACK	IISI, Finished Cold Roll. Coil, BF Route	0.2100	2	0.4200
17.28.2	GUIDE - DRAWER TRACK	IISI, Finished Cold Roll. Coil, BF Route	0.2100	2	0.4200
17.28.3	SCREW - TAPPING	Screw, self-tapping	0.1000	16	1.6000
17.28.4	Purchased plywood Drawer	plywood CORIM data	7.2230	2	14.4460
17.29	PIN - DOWEL	Red oak I, US	0.1000	4	0.4000
17.3	HARDWARE PACKAGE		1.3610	1	0.0000
17.30.1	TRAY	Polystyrene (high impact) APME	0.5300	1	0.5300
17.30.2	SUPPORT - ACCESSORY	ABS	0.0010	4	0.0040
17.30.3	RAIL	IISI, Finished Cold Roll. Coil, BF Route	0.5000	1	0.5000
17.30.4	DIVIDER - DRAWER	Red oak I, US	0.1570	2	0.3140
17.31	SCREW - METRIC	IISI, Engineering Steel, EAF Route	0.1000	8	0.8000
19	BOOKLET	Paper woody U B250 (1998), US	0.1000	1	0.1000

Appendix D

Siento: Complete Life-Cycle Inventory

Compartment	Substance	Unit	Qty.
Air	CO2	kg	6.35E+01
Air	CO2 (fossil)	kg	3.92E+01
Air	CO2 (non-fossil)	kg	4.10E+00
Air	water	kg	1.80E+00
Air	CO	kg	4.36E-01
Air	CxHy	kg	3.97E-01
Air	SOx	kg	3.17E-01
Air	SO2	kg	2.66E-01
Air	methane	kg	2.34E-01
Air	NOx	kg	2.13E-01
Air	dust (SPM)	kg	1.16E-01
Air	NO2	kg	1.10E-01
Air	O2	kg	8.32E-02
Air	particulates (unspecified)	kg	7.35E-02
Air	non methane VOC	kg	4.91E-02
Air	organic substances	kg	4.20E-02
Air	hydrocarbons (misc)	kg	2.91E-02
Air	dust (PM10)	kg	2.40E-02
Air	N2O	kg	2.05E-02
Air	particulates (PM10)	kg	1.31E-02
Air	ethylene glycol	kg	1.03E-02
Air	H2	kg	6.21E-03
Air	toluene	kg	3.44E-03
Air	soot	kg	3.03E-03
Air	HCl	kg	2.88E-03
Air	aldehydes	kg	2.22E-03
Air	K	kg	1.52E-03
Air	VOC	kg	1.49E-03
Air	ammonia	kg	1.25E-03
Air	NOx (as NO2)	kg	9.38E-04
Air	Zn	kg	9.10E-04
Air	Cl2	kg	7.92E-04
Air	Aromatic HC	kg	5.69E-04
Air	H2S	kg	4.15E-04
Air	Cu	kg	1.64E-04
Air	dust (coarse)	kg	1.33E-04
Air	SOx (as SO2)	kg	1.33E-04
Air	HF	kg	1.21E-04
Air	CFC (soft)	kg	1.02E-04
Air	total reduced sulfur	kg	9.39E-05
Air	phenol	kg	7.86E-05
Air	Al	kg	7.62E-05
Air	formaldehyde	kg	6.50E-05
Air	benzene	kg	5.46E-05
Air	Pb	kg	5.17E-05
Air	Cr	kg	4.78E-05
Air	Na	kg	3.51E-05
Air	metals	kg	3.25E-05
Air	organo-chlorine	kg	3.25E-05

Air	dust	kg	3.03E-05
Air	Mn	kg	2.97E-05
Air	Sn	kg	2.71E-05
Air	H2SO4	kg	2.62E-05
Air	Ni	kg	2.04E-05
Air	trichloroethene	kg	1.59E-05
Air	F2	kg	1.29E-05
Air	ethylene	kg	1.24E-05
Air	Ba	kg	8.58E-06
Air	Fe	kg	8.58E-06
Air	propylene	kg	8.23E-06
Air	HCN	kg	7.90E-06
Air	PAH's	kg	7.40E-06
Air	acetaldehyde	kg	5.85E-06
Air	naphthalene	kg	4.69E-06
Air	ethylbenzene	kg	3.35E-06
Air	1,1,1-trichloroethane	kg	3.15E-06
Air	kerosene	kg	2.64E-06
Air	As	kg	2.53E-06
Air	CS2	kg	2.50E-06
Air	Cd	kg	1.53E-06
Air	boron monoxide	kg	1.48E-06
Air	Sb	kg	1.41E-06
Air	Hg	kg	1.38E-06
Air	cobalt	kg	1.32E-06
Air	CxHy aromatic	kg	1.26E-06
Air	styrene	kg	9.46E-07
Air	xylene	kg	7.72E-07
Air	Se	kg	7.60E-07
Air	dichloromethane	kg	4.42E-07
Air	tar	kg	4.17E-07
Air	hexachlorobiphenyl	kg	2.58E-07
Air	CxHy chloro	kg	2.54E-07
Air	Mo	kg	2.32E-07
Air	tetrachloromethane	kg	1.68E-07
Air	Be	kg	1.43E-07
Air	V	kg	1.28E-07
Air	acrolein	kg	1.04E-07
Air	tetrachloroethene	kg	9.92E-08
Air	unspecified emission	kg	5.55E-08
Air	Ag	kg	2.42E-08
Air	n-nitrodimethylamine	kg	2.20E-08
Air	PCB's	kg	7.16E-09
Air	chlorophenols	kg	3.15E-09
Air	HALON-1301	kg	3.13E-09
Air	CxHy halogenated	kg	1.76E-09
Air	pentachlorophenol	kg	5.45E-10
Air	dioxin (TEQ)	kg	1.29E-10
Non mat.	radioactive substance to air	Bq	1.86E+05
Non mat.	radioactive substance to water	Bq	3.60E+02
Non mat.	Occup. as industrial area	m2a	4.48E-02
Non mat.	Conv. to continuous urban land	m2	4.74E-04
Non mat.	Conv. to industrial area	m2	6.19E-06
Raw	water (surface, for process.)	kg	6.31E+02
Raw	water	kg	4.99E+02
Raw	energy from fossil	MJ	2.80E+02

Raw	barrage water	kg	2.30E+02
Raw	water (drinking, for process.)	kg	1.59E+02
Raw	unspecified energy	MJ	1.04E+02
Raw	water (sea, for processing)	kg	7.58E+01
Raw	energy from non-fossil	MJ	5.66E+01
Raw	water (well, for processing)	kg	3.09E+01
Raw	aluminium scrap	kg	1.02E+01
Raw	iron (in ore)	kg	9.05E+00
Raw	coal FAL	kg	8.30E+00
Raw	energy from hydro power	MJ	8.01E+00
Raw	steel scrap	kg	7.60E+00
Raw	crude oil ETH	kg	6.28E+00
Raw	iron (ore)	kg	4.87E+00
Raw	wood for fiber (feedstock) FAL	kg	4.54E+00
Raw	crude oil FAL	kg	4.13E+00
Raw	bauxite	kg	4.07E+00
Raw	wood/wood wastes FAL	kg	3.93E+00
Raw	NaCl	kg	3.81E+00
Raw	air	kg	3.07E+00
Raw	coal ETH	kg	2.57E+00
Raw	natural gas FAL	kg	2.56E+00
Raw	energy from uranium	MJ	2.45E+00
Raw	limestone	kg	2.30E+00
Raw	energy (undef.)	MJ	2.05E+00
Raw	silica	kg	1.51E+00
Raw	scrap, external	kg	9.88E-01
Raw	nitrogen	kg	9.24E-01
Raw	biomass	kg	5.98E-01
Raw	zinc (in ore)	kg	4.76E-01
Raw	oxygen	kg	4.59E-01
Raw	additions	kg	4.52E-01
Raw	coal	kg	3.59E-01
Raw	wood (dry matter) ETH	kg	3.09E-01
Raw	calcined coke	kg	2.92E-01
Raw	lignite	kg	2.77E-01
Raw	sulphur (elemental)	kg	2.72E-01
Raw	alloys	kg	2.08E-01
Raw	lignite ETH	kg	2.05E-01
Raw	natural gas	kg	1.97E-01
Raw	dolomite	kg	1.67E-01
Raw	crude oil	kg	1.57E-01
Raw	NaOH	kg	1.17E-01
Raw	cardboard	kg	8.60E-02
Raw	pitch	kg	8.23E-02
Raw	water treatment chemicals	kg	8.15E-02
Raw	lubricating oil	kg	7.43E-02
Raw	lime	kg	7.03E-02
Raw	nickel (in ore)	kg	6.91E-02
Raw	pot. energy hydropower	MJ	5.61E-02
Raw	running oil	kg	3.21E-02
Raw	sand	kg	2.95E-02
Raw	KCl	kg	2.37E-02
Raw	Na2SO4	kg	2.08E-02
Raw	uranium (ore)	kg	1.02E-02
Raw	natural gas ETH	m3	7.76E-03
Raw	soda ash	kg	6.74E-03

Raw	phosphate (as P2O5)	kg	4.50E-03
Raw	Peat	kg	4.14E-03
Raw	soda	kg	3.24E-03
Raw	feldspar	kg	2.07E-03
Raw	phosphate (ore)	kg	1.09E-03
Raw	process water	m3	1.05E-03
Raw	sulphur	kg	1.02E-03
Raw	baryte	kg	9.52E-04
Raw	ulexite	kg	7.41E-04
Raw	sylvinite	kg	5.33E-04
Raw	bentonite	kg	4.14E-04
Raw	P2O5	kg	3.09E-04
Raw	boron (in ore)	kg	1.85E-04
Raw	olivine	kg	1.27E-04
Raw	shale	kg	1.15E-04
Raw	rock salt	kg	1.05E-04
Raw	seed corn	kg	6.10E-05
Raw	fluorspar	kg	6.06E-05
Raw	gravel	kg	4.81E-05
Raw	calcium sulphate	kg	4.05E-05
Raw	chromium (in ore)	kg	3.42E-05
Raw	lead (in ore)	kg	2.62E-05
Raw	ferromanganese	kg	1.33E-05
Raw	uranium FAL	kg	1.21E-05
Raw	pesticides	kg	1.14E-05
Raw	wood	kg	1.12E-05
Raw	rutile	kg	1.00E-05
Raw	clay	kg	1.00E-05
Raw	manganese (in ore)	kg	6.30E-06
Raw	mercury (in ore)	kg	5.00E-06
Raw	sulphur (bonded)	kg	3.34E-06
Raw	copper (in ore)	kg	1.58E-06
Raw	magnesium (in ore)	kg	7.72E-07
Raw	uranium (in ore)	kg	4.50E-07
Raw	SO2 secondary	kg	9.53E-08
Raw	iridium (in ore)	kg	8.13E-08
Raw	clay minerals	kg	0.00E+00
Soil	carbon	kg	2.17E-06
Soil	N-tot	kg	1.70E-08
Soil	Hg	kg	7.94E-11
Soil	Cd	kg	9.46E-12
Soil	Pb	kg	2.63E-13
Soil	Zn	kg	9.24E-15
Waste	final waste (inert)	kg	1.41E+01
Waste	solid waste	kg	1.12E+01
Waste	aluminium waste	kg	9.48E+00
Waste	unspecified	kg	7.87E+00
Waste	steel scrap	kg	4.43E+00
Waste	produc. waste (not inert)	kg	4.29E+00
Waste	paper/board packaging	kg	2.25E+00
Waste	slag	kg	1.73E+00
Waste	waste back to mine	kg	4.71E-01
Waste	plastics waste	kg	4.53E-01
Waste	mineral waste	kg	3.80E-01
Waste	zinc	kg	2.86E-01
Waste	metal scrap	kg	2.71E-01

Waste	aluminium scrap	kg	2.14E-01
Waste	slags/ash	kg	2.14E-01
Waste	Unspecified refuse	kg	1.76E-01
Waste	chemical waste (regulated)	kg	1.13E-01
Waste	wood waste	kg	1.06E-01
Waste	chemical waste	kg	8.03E-02
Waste	industrial waste	kg	6.22E-02
Waste	waste in incineration	kg	5.46E-02
Waste	PE waste	kg	3.12E-02
Waste	chemical waste (inert)	kg	9.49E-03
Waste	waste to recycling	kg	7.90E-03
Waste	coal tailings	kg	1.60E-03
Waste	metals	kg	9.79E-04
Waste	construction waste	kg	2.01E-04
Waste	inorganic general	kg	6.59E-05
Waste	putrescibles	kg	6.67E-06
Waste	Municipal solid waste	kg	-9.53E-02
Water	Cl-	kg	2.09E+00
Water	Na	kg	1.08E+00
Water	calcium compounds	kg	3.00E-01
Water	suspended solids	kg	1.28E-01
Water	dissolved solids	kg	1.17E-01
Water	COD	kg	4.99E-02
Water	sulphate	kg	4.35E-02
Water	nitrate	kg	2.28E-02
Water	BOD	kg	1.32E-02
Water	HCl	kg	8.33E-03
Water	nitrogen	kg	6.57E-03
Water	carbonate	kg	4.44E-03
Water	dissolved substances	kg	3.81E-03
Water	suspended substances	kg	3.49E-03
Water	oil	kg	2.77E-03
Water	Cr	kg	2.45E-03
Water	TOC	kg	2.37E-03
Water	P	kg	2.24E-03
Water	crude oil	kg	2.14E-03
Water	Fe	kg	1.94E-03
Water	NH4+	kg	1.59E-03
Water	sulphates	kg	1.21E-03
Water	other organics	kg	8.72E-04
Water	B	kg	8.53E-04
Water	dissolved organics	kg	7.81E-04
Water	NH3 (as N)	kg	6.00E-04
Water	anorg. dissolved subst.	kg	5.58E-04
Water	phosphate	kg	5.06E-04
Water	Cu	kg	5.06E-04
Water	Acid as H+	kg	4.75E-04
Water	N-tot	kg	4.46E-04
Water	sulphide	kg	4.31E-04
Water	metallic ions	kg	4.30E-04
Water	Al	kg	3.84E-04
Water	Mg	kg	3.82E-04
Water	Mn	kg	3.70E-04
Water	K	kg	3.25E-04
Water	ClO3-	kg	2.87E-04
Water	hydrocarbons (misc)	kg	2.77E-04

Water	Pb	kg	2.17E-04
Water	P-tot	kg	1.47E-04
Water	F2	kg	1.38E-04
Water	NH3	kg	1.19E-04
Water	acids (unspecified)	kg	1.12E-04
Water	Zn	kg	1.02E-04
Water	H2SO4	kg	9.34E-05
Water	detergent/oil	kg	9.25E-05
Water	organic carbon	kg	6.35E-05
Water	AOX	kg	5.75E-05
Water	CxHy	kg	5.68E-05
Water	Ni	kg	5.52E-05
Water	fats/oils	kg	1.75E-05
Water	fluoride ions	kg	1.31E-05
Water	phenols	kg	1.01E-05
Water	H2	kg	9.33E-06
Water	phenol	kg	8.39E-06
Water	organo-chlorine	kg	5.77E-06
Water	Sb	kg	5.56E-06
Water	Cd	kg	5.56E-06
Water	V	kg	4.67E-06
Water	Co	kg	4.14E-06
Water	As	kg	4.11E-06
Water	Mo	kg	3.52E-06
Water	CN-	kg	2.50E-06
Water	Dissolved chlorine	kg	2.50E-06
Water	calcium ions	kg	2.28E-06
Water	Ba	kg	1.79E-06
Water	P2O5	kg	1.26E-06
Water	CxHy aromatic	kg	5.63E-07
Water	cyanide	kg	4.26E-07
Water	Kjeldahl-N	kg	2.19E-07
Water	Ag	kg	1.89E-07
Water	chromate	kg	1.26E-07
Water	toluene	kg	7.83E-08
Water	DOC	kg	3.16E-08
Water	Hg	kg	1.68E-08
Water	Be	kg	1.26E-08
Water	PAH's	kg	8.55E-09
Water	CxHy chloro	kg	6.08E-10
Water	waste water (vol)	m3	1.43E-10
Water	herbicides	kg	8.32E-12
Water	pesticides	kg	4.23E-12

Appendix E

Garland: Complete Life-Cycle Inventory

Compartment	Substance	Unit	Qty.
Air	CO2 (fossil)	kg	1.54E+02
Air	CO2	kg	5.31E+01
Air	water	kg	1.49E+01
Air	CO2 (non-fossil)	kg	1.37E+01
Air	SOx	kg	1.26E+00
Air	CO	kg	1.24E+00
Air	NOx	kg	8.40E-01
Air	non methane VOC	kg	3.82E-01
Air	methane	kg	3.13E-01
Air	organic substances	kg	2.35E-01
Air	particulates (unspecified)	kg	1.25E-01
Air	O2	kg	8.63E-02
Air	SO2	kg	8.47E-02
Air	particulates (PM10)	kg	8.12E-02
Air	NO2	kg	7.12E-02
Air	CxHy	kg	4.50E-02
Air	N2O	kg	1.27E-02
Air	aldehydes	kg	1.25E-02
Air	HCl	kg	6.94E-03
Air	VOC	kg	3.49E-03
Air	hydrocarbons (misc)	kg	3.43E-03
Air	H2	kg	2.55E-03
Air	ammonia	kg	2.11E-03
Air	K	kg	1.97E-03
Air	dust (PM10)	kg	1.56E-03
Air	H2S	kg	1.48E-03
Air	ureum	kg	1.02E-03
Air	HF	kg	6.84E-04
Air	formaldehyde	kg	6.19E-04
Air	soot	kg	2.95E-04
Air	Zn	kg	2.17E-04
Air	Cu	kg	2.01E-04
Air	benzene	kg	1.79E-04
Air	NOx (as NO2)	kg	1.62E-04
Air	dust (SPM)	kg	1.30E-04
Air	Cr	kg	1.18E-04
Air	Cl2	kg	1.12E-04
Air	phenol	kg	1.11E-04
Air	total reduced sulfur	kg	1.04E-04
Air	Pb	kg	9.68E-05
Air	Ni	kg	5.97E-05
Air	SOx (as SO2)	kg	5.33E-05
Air	Mn	kg	5.00E-05
Air	Aromatic HC	kg	4.83E-05
Air	Na	kg	4.54E-05
Air	kerosene	kg	2.48E-05
Air	metals	kg	2.18E-05
Air	styrene	kg	2.09E-05

Air	toluene	kg	1.23E-05
Air	Ba	kg	1.11E-05
Air	Fe	kg	1.11E-05
Air	dust	kg	9.91E-06
Air	acetaldehyde	kg	7.57E-06
Air	Se	kg	7.47E-06
Air	odorous sulfur	kg	7.30E-06
Air	As	kg	7.25E-06
Air	vinyl chloride	kg	6.37E-06
Air	naphthalene	kg	6.13E-06
Air	ethylene	kg	5.09E-06
Air	organo-chlorine	kg	4.45E-06
Air	Cd	kg	4.43E-06
Air	cobalt	kg	4.41E-06
Air	Hg	kg	4.17E-06
Air	dichloromethane	kg	4.14E-06
Air	trichloroethene	kg	3.94E-06
Air	dichloroethane	kg	3.92E-06
Air	ethylbenzene	kg	3.86E-06
Air	H2SO4	kg	3.40E-06
Air	propylene	kg	3.13E-06
Air	CFC (soft)	kg	3.05E-06
Air	Sb	kg	2.93E-06
Air	tetrachloromethane	kg	1.56E-06
Air	PAH's	kg	1.42E-06
Air	acrolein	kg	9.77E-07
Air	tetrachloroethene	kg	9.31E-07
Air	1,1,1-trichloroethane	kg	6.03E-07
Air	Be	kg	6.02E-07
Air	Mo	kg	2.66E-07
Air	xylene	kg	2.40E-07
Air	CxHy aromatic	kg	2.30E-07
Air	CS2	kg	2.27E-07
Air	n-nitrodimethylamine	kg	2.06E-07
Air	V	kg	2.00E-07
Air	hexachlorobiphenyl	kg	4.94E-08
Air	Ag	kg	2.30E-08
Air	PCB's	kg	1.37E-09
Air	chlorophenols	kg	6.03E-10
Air	CxHy halogenated	kg	4.23E-10
Air	dioxin (TEQ)	kg	3.87E-10
Air	HALON-1301	kg	2.10E-10
Air	pentachlorophenol	kg	1.04E-10
Air	F2	kg	0.00E+00
Non mat.	radioactive substance to air	Bq	1.38E+06
Non mat.	Occup. as rail/road area	m2a	1.61E+02
Non mat.	radioactive substance to water	Bq	2.93E+00
Non mat.	Occup. as industrial area	m2a	5.12E-02
Non mat.	Conv. to industrial area	m2	9.63E-06
Raw	water	kg	4.87E+02
Raw	saw dust (waste)	kg	7.47E+01
Raw	energy from hydro power	MJ	5.51E+01
Raw	water (surface, for process.)	kg	4.69E+01

Raw	coal FAL	kg	4.39E+01
Raw	wood (cherry)	kg	3.58E+01
Raw	iron (in ore)	kg	3.28E+01
Raw	crude oil FAL	kg	2.17E+01
Raw	natural gas FAL	kg	2.10E+01
Raw	wood (yellow pine)	kg	1.88E+01
Raw	water (drinking, for process.)	kg	1.23E+01
Raw	water (sea, for processing)	kg	1.10E+01
Raw	steel scrap	kg	7.38E+00
Raw	wood for fiber (feedstock) FAL	kg	7.30E+00
Raw	wood/wood wastes FAL	kg	5.11E+00
Raw	wood (red oak)	kg	2.41E+00
Raw	limestone	kg	2.33E+00
Raw	natural gas	kg	1.13E+00
Raw	crude oil ETH	kg	1.00E+00
Raw	scrap, external	kg	8.23E-01
Raw	wood	kg	6.01E-01
Raw	dolomite	kg	5.38E-01
Raw	energy (undef.)	MJ	4.80E-01
Raw	NaCl	kg	3.37E-01
Raw	coal ETH	kg	1.74E-01
Raw	nitrogen	kg	1.37E-01
Raw	water (well, for processing)	kg	1.28E-01
Raw	crude oil	kg	1.18E-01
Raw	salt	kg	5.72E-02
Raw	oxygen	kg	3.93E-02
Raw	biomass	kg	2.72E-02
Raw	Na2SO4	kg	2.48E-02
Raw	zinc (in ore)	kg	1.45E-02
Raw	lignite ETH	kg	8.68E-03
Raw	soda ash	kg	5.61E-03
Raw	crude oil IDEMAT	kg	5.24E-03
Raw	wood (dry matter) ETH	kg	4.23E-03
Raw	KCl	kg	1.53E-03
Raw	phosphate (ore)	kg	1.46E-03
Raw	sulphur	kg	1.35E-03
Raw	natural gas ETH	m3	8.60E-04
Raw	sulphur (elemental)	kg	7.51E-04
Raw	sylvinite	kg	7.17E-04
Raw	sand	kg	4.59E-04
Raw	pot. energy hydropower	MJ	3.57E-04
Raw	Peat	kg	3.07E-04
Raw	bauxite	kg	2.99E-04
Raw	process water	m3	2.55E-04
Raw	phosphate (as P2O5)	kg	2.20E-04
Raw	silica	kg	1.70E-04
Raw	uranium FAL	kg	1.12E-04
Raw	rock salt	kg	9.86E-05
Raw	seed corn	kg	8.21E-05
Raw	lignite	kg	6.93E-05
Raw	bentonite	kg	6.88E-05
Raw	feldspar	kg	6.80E-05
Raw	copper (in ore)	kg	4.66E-05
Raw	shale	kg	1.96E-05

Raw	pesticides	kg	1.53E-05
Raw	olivine	kg	8.28E-06
Raw	calcium sulphate	kg	7.21E-06
Raw	fluorspar	kg	6.24E-06
Raw	nickel (in ore)	kg	5.53E-06
Raw	lead (in ore)	kg	3.58E-06
Raw	gravel	kg	3.43E-06
Raw	lubricating oil	kg	2.68E-06
Raw	clay	kg	1.30E-06
Raw	chromium (in ore)	kg	1.15E-06
Raw	ferromanganese	kg	7.89E-07
Raw	mercury (in ore)	kg	6.99E-07
Raw	sulphur (bonded)	kg	2.40E-07
Raw	SO2 secondary	kg	8.99E-08
Raw	iridium (in ore)	kg	7.67E-08
Raw	uranium (in ore)	kg	5.73E-09
Waste	final waste (inert)	kg	6.31E+01
Waste	solid waste	kg	4.69E+01
Waste	unspecified	kg	3.40E+01
Waste	wood waste	kg	1.82E+01
Waste	slag	kg	1.64E+01
Waste	steel scrap	kg	6.12E+00
Waste	wood (sawdust)	kg	2.48E+00
Waste	paper/board packaging	kg	2.12E+00
Waste	plastics waste	kg	6.68E-02
Waste	waste back to mine	kg	3.47E-02
Waste	PE waste	kg	2.14E-02
Waste	mineral waste	kg	1.92E-02
Waste	slags/ash	kg	1.44E-02
Waste	ash	kg	1.21E-02
Waste	waste in incineration	kg	7.38E-03
Waste	chemical waste (regulated)	kg	6.99E-03
Waste	industrial waste	kg	3.85E-03
Waste	chemical waste	kg	3.26E-03
Waste	chemical waste (inert)	kg	2.27E-03
Waste	coal tailings	kg	2.02E-03
Waste	Unspecified refuse	kg	1.45E-03
Waste	waste to recycling	kg	4.53E-04
Waste	produc. waste (not inert)	kg	1.84E-04
Waste	construction waste	kg	4.40E-05
Waste	metals	kg	3.93E-05
Waste	putrescibles	kg	4.81E-07
Waste	plastics packaging	kg	2.40E-07
Waste	Municipal solid waste	kg	-6.22E-03
Water	dissolved solids	kg	1.06E+00
Water	Cl-	kg	1.72E-01
Water	suspended solids	kg	7.74E-02
Water	water	kg	7.38E-02
Water	Na	kg	6.58E-02
Water	COD	kg	5.63E-02
Water	sulphate	kg	5.14E-02
Water	oil	kg	1.94E-02
Water	calcium compounds	kg	1.30E-02

Water	BOD	kg	1.20E-02
Water	suspended substances	kg	5.62E-03
Water	Fe	kg	5.08E-03
Water	other organics	kg	3.52E-03
Water	B	kg	2.94E-03
Water	Mn	kg	2.38E-03
Water	NH3 (as N)	kg	1.69E-03
Water	dissolved substances	kg	1.50E-03
Water	N-tot	kg	1.20E-03
Water	Cu	kg	7.78E-04
Water	H2SO4	kg	7.34E-04
Water	phosphate	kg	7.11E-04
Water	nitrate	kg	5.63E-04
Water	metallic ions	kg	5.23E-04
Water	Al	kg	3.67E-04
Water	sulphide	kg	3.60E-04
Water	carbonate	kg	3.40E-04
Water	anorg. dissolved subst.	kg	2.98E-04
Water	NH3	kg	2.74E-04
Water	TOC	kg	2.56E-04
Water	P-tot	kg	2.45E-04
Water	sulphates	kg	2.16E-04
Water	nitrogen	kg	2.07E-04
Water	Cr	kg	1.42E-04
Water	acids (unspecified)	kg	1.09E-04
Water	fluoride ions	kg	9.87E-05
Water	Zn	kg	9.80E-05
Water	dissolved organics	kg	9.74E-05
Water	P	kg	8.98E-05
Water	Ni	kg	8.30E-05
Water	organic carbon	kg	5.44E-05
Water	Cd	kg	4.90E-05
Water	NH4+	kg	3.35E-05
Water	ClO3-	kg	2.95E-05
Water	K	kg	2.76E-05
Water	calcium ions	kg	2.13E-05
Water	Mg	kg	2.03E-05
Water	chlorate ion (ClO3-)	kg	1.96E-05
Water	crude oil	kg	1.95E-05
Water	detergent/oil	kg	1.45E-05
Water	hydrocarbons (misc)	kg	1.06E-05
Water	Sb	kg	7.92E-06
Water	V	kg	7.24E-06
Water	Acid as H+	kg	6.89E-06
Water	As	kg	6.39E-06
Water	Co	kg	6.33E-06
Water	phenol	kg	5.61E-06
Water	Pb	kg	4.45E-06
Water	Mo	kg	4.18E-06
Water	AOX	kg	2.80E-06
Water	chromate	kg	1.97E-06
Water	fats/oils	kg	1.20E-06
Water	phenols	kg	1.13E-06
Water	CxHy	kg	9.06E-07

Water	vinyl chloride	kg	8.16E-07
Water	organo-chlorine	kg	6.80E-07
Water	Dissolved chlorine	kg	4.72E-07
Water	H2	kg	2.45E-07
Water	benzene	kg	2.40E-07
Water	dichloroethane	kg	1.63E-07
Water	Ag	kg	1.55E-07
Water	Ba	kg	1.31E-07
Water	organochloro pesticide	kg	8.16E-08
Water	cyanide	kg	7.16E-08
Water	CxHy aromatic	kg	3.85E-08
Water	Kjeldahl-N	kg	1.61E-08
Water	Hg	kg	1.44E-08
Water	Be	kg	1.43E-08
Water	DOC	kg	8.54E-09
Water	toluene	kg	5.33E-09
Water	sodium dichromate	kg	1.24E-09
Water	PAH's	kg	5.76E-10
Water	waste water (vol)	m3	1.35E-10
Water	CxHy chloro	kg	4.74E-11

Appendix F

AirTouch: Complete Life-Cycle Inventory

Compartment	Substance	Unit	Qty.
Air	CO2 (fossil)	kg	1.64E+02
Air	CO2	kg	5.14E+01
Air	CO2 (non-fossil)	kg	4.04E+00
Air	CO	kg	1.56E+00
Air	SOx	kg	1.23E+00
Air	water	kg	1.17E+00
Air	NOx	kg	7.03E-01
Air	particulates (unspecified)	kg	5.25E-01
Air	O2	kg	2.18E-01
Air	non methane VOC	kg	1.18E-01
Air	organic substances	kg	9.68E-02
Air	methane	kg	8.51E-02
Air	NO2	kg	7.31E-02
Air	SO2	kg	7.00E-02
Air	particulates (PM10)	kg	2.70E-02
Air	CxHy	kg	1.13E-02
Air	N2O	kg	9.38E-03
Air	VOC	kg	5.10E-03
Air	aldehydes	kg	5.04E-03
Air	dust (SPM)	kg	3.89E-03
Air	HCl	kg	2.28E-03
Air	NOx (as NO2)	kg	1.86E-03
Air	K	kg	1.50E-03
Air	H2	kg	1.35E-03
Air	H2S	kg	1.25E-03
Air	hydrocarbons (misc)	kg	1.24E-03
Air	ammonia	kg	5.42E-04
Air	dust (PM10)	kg	4.43E-04
Air	Zn	kg	3.55E-04
Air	soot	kg	3.14E-04
Air	Cu	kg	2.72E-04
Air	ureum	kg	2.12E-04
Air	SOx (as SO2)	kg	2.09E-04
Air	benzene	kg	2.06E-04
Air	Cr	kg	1.09E-04
Air	Pb	kg	9.41E-05
Air	odorous sulfur	kg	8.61E-05
Air	phenol	kg	8.60E-05
Air	total reduced sulfur	kg	5.85E-05
Air	formaldehyde	kg	5.70E-05
Air	HF	kg	5.56E-05
Air	dust	kg	5.16E-05
Air	Cl2	kg	5.12E-05
Air	Ni	kg	4.18E-05
Air	Mn	kg	3.73E-05
Air	Na	kg	3.46E-05
Air	Cr (III)	kg	2.36E-05
Air	Aromatic HC	kg	2.05E-05

Air	vinyl chloride	kg	1.68E-05
Air	F2	kg	1.59E-05
Air	toluene	kg	1.30E-05
Air	dichloroethane	kg	1.03E-05
Air	metals	kg	8.70E-06
Air	Ba	kg	8.45E-06
Air	Fe	kg	8.45E-06
Air	acetaldehyde	kg	5.76E-06
Air	naphthalene	kg	4.62E-06
Air	ethylene	kg	3.77E-06
Air	As	kg	3.61E-06
Air	CFC (soft)	kg	3.23E-06
Air	Hg	kg	3.07E-06
Air	Sb	kg	2.81E-06
Air	cobalt	kg	2.72E-06
Air	Cd	kg	2.71E-06
Air	CxHy aromatic	kg	2.49E-06
Air	organo-chlorine	kg	2.15E-06
Air	trichloroethene	kg	1.98E-06
Air	kerosene	kg	1.96E-06
Air	Mo	kg	1.74E-06
Air	Se	kg	6.42E-07
Air	propylene	kg	5.76E-07
Air	1,1,1-trichloroethane	kg	3.82E-07
Air	dichloromethane	kg	3.30E-07
Air	ethylbenzene	kg	3.12E-07
Air	V	kg	2.70E-07
Air	ethylene glycol butyl ether	kg	2.08E-07
Air	tetrachloromethane	kg	1.37E-07
Air	Be	kg	1.21E-07
Air	styrene	kg	1.15E-07
Air	propylene glycol	kg	1.04E-07
Air	acrolein	kg	7.74E-08
Air	tetrachloroethene	kg	7.40E-08
Air	hexachlorobiphenyl	kg	3.12E-08
Air	Ag	kg	2.98E-08
Air	Cr (VI)	kg	2.52E-08
Air	n-nitrodimethylamine	kg	1.64E-08
Air	HALON-1301	kg	6.80E-09
Air	CxHy halogenated	kg	3.29E-09
Air	PAH's	kg	2.69E-09
Air	PCB's	kg	8.67E-10
Air	chlorophenols	kg	3.82E-10
Air	dioxin (TEQ)	kg	3.67E-10
Air	pentachlorophenol	kg	6.59E-11
Non mat.	radioactive substance to air	Bq	1.98E+05
Non mat.	radioactive substance to water	Bq	8.21E+02
Non mat.	Occup. as rail/road area	m2a	2.37E-01
Non mat.	Occup. as industrial area	m2a	5.51E-02
Non mat.	Conv. to continuous urban land	m2	1.20E-04
Non mat.	Conv. to industrial area	m2	9.99E-06
Raw	energy from fossil	MJ	1.43E+03
Raw	energy from non-fossil	MJ	7.01E+02

Raw	water	kg	5.78E+02
Raw	bauxite	kg	5.16E+01
Raw	iron (in ore)	kg	2.73E+01
Raw	steel scrap	kg	2.03E+01
Raw	coal FAL	kg	1.56E+01
Raw	saw dust (waste)	kg	1.55E+01
Raw	energy (undef.)	MJ	9.10E+00
Raw	barrage water	kg	8.73E+00
Raw	crude oil FAL	kg	8.57E+00
Raw	water (surface, for process.)	kg	7.92E+00
Raw	natural gas FAL	kg	7.15E+00
Raw	wood for fiber (feedstock) FAL	kg	5.29E+00
Raw	aluminium scrap	kg	4.02E+00
Raw	wood/wood wastes FAL	kg	3.87E+00
Raw	calcined coke	kg	3.85E+00
Raw	energy from hydro power	MJ	3.71E+00
Raw	water (sea, for processing)	kg	2.79E+00
Raw	limestone	kg	1.59E+00
Raw	NaOH	kg	1.50E+00
Raw	pitch	kg	1.08E+00
Raw	water (drinking, for process.)	kg	1.06E+00
Raw	lubricating oil	kg	9.72E-01
Raw	lime	kg	9.31E-01
Raw	scrap, external	kg	6.30E-01
Raw	dolomite	kg	5.95E-01
Raw	crude oil ETH	kg	3.74E-01
Raw	silica	kg	2.98E-01
Raw	energy from uranium	MJ	2.76E-01
Raw	natural gas	kg	2.59E-01
Raw	iron (ore)	kg	2.52E-01
Raw	NaCl	kg	2.19E-01
Raw	water (well, for processing)	kg	1.93E-01
Raw	air	kg	1.92E-01
Raw	pot. energy hydropower	MJ	1.28E-01
Raw	wood	kg	1.04E-01
Raw	salt	kg	9.47E-02
Raw	sand	kg	9.31E-02
Raw	coal ETH	kg	7.82E-02
Raw	alloys	kg	7.78E-02
Raw	nitrogen	kg	4.70E-02
Raw	water treatment chemicals	kg	3.08E-02
Raw	coal	kg	2.63E-02
Raw	crude oil	kg	2.43E-02
Raw	chromium (ore)	kg	2.19E-02
Raw	cardboard	kg	2.06E-02
Raw	oxygen	kg	1.94E-02
Raw	lignite	kg	1.59E-02
Raw	Na2SO4	kg	1.30E-02
Raw	manganese (in ore)	kg	1.19E-02
Raw	chromium (in ore)	kg	1.14E-02
Raw	wood (dry matter) ETH	kg	1.05E-02
Raw	biomass	kg	6.37E-03
Raw	silicon (in SiO2)	kg	4.35E-03
Raw	soda ash	kg	4.20E-03

Raw	nickel (ore)	kg	4.09E-03
Raw	process water	m3	1.97E-03
Raw	vanadium (in ore)	kg	1.63E-03
Raw	manganese (ore)	kg	1.31E-03
Raw	phosphate (ore)	kg	1.21E-03
Raw	sulphur	kg	6.36E-04
Raw	sylvinite	kg	5.92E-04
Raw	natural gas ETH	m3	3.28E-04
Raw	Peat	kg	3.19E-04
Raw	molybdenum (ore)	kg	2.78E-04
Raw	KCl	kg	2.15E-04
Raw	treatment salts	kg	1.29E-04
Raw	lignite ETH	kg	1.27E-04
Raw	uranium (ore)	kg	1.17E-04
Raw	rolling oil	kg	6.93E-05
Raw	seed corn	kg	6.78E-05
Raw	rock salt	kg	6.51E-05
Raw	baryte	kg	4.52E-05
Raw	copper (in ore)	kg	2.09E-05
Raw	bentonite	kg	1.91E-05
Raw	pesticides	kg	1.26E-05
Raw	uranium FAL	kg	9.03E-06
Raw	shale	kg	5.33E-06
Raw	olivine	kg	3.79E-06
Raw	calcium sulphate	kg	2.04E-06
Raw	gravel	kg	1.57E-06
Raw	uranium (in ore)	kg	1.02E-06
Raw	lead (in ore)	kg	7.49E-07
Raw	mercury (in ore)	kg	6.45E-07
Raw	clay	kg	4.30E-07
Raw	fluorspar	kg	4.30E-07
Raw	phosphate (as P2O5)	kg	4.30E-07
Raw	ferromanganese	kg	2.15E-07
Raw	SO2 secondary	kg	5.94E-08
Raw	iridium (in ore)	kg	5.07E-08
Raw	clay minerals	kg	0.00E+00
Raw	sulphur (elemental)	kg	-6.92E-05
Raw	zinc (in ore)	kg	-1.05E-01
Waste	aluminium waste	kg	5.04E+01
Waste	final waste (inert)	kg	2.90E+01
Waste	solid waste	kg	2.89E+01
Waste	unspecified	kg	1.57E+01
Waste	steel scrap	kg	9.02E+00
Waste	slag	kg	5.72E+00
Waste	wood waste	kg	1.91E+00
Waste	paper/board packaging	kg	1.40E+00
Waste	plastics waste	kg	2.86E-02
Waste	PE waste	kg	2.52E-02
Waste	waste back to mine	kg	1.66E-02
Waste	slags/ash	kg	9.98E-03
Waste	mineral waste	kg	6.92E-03
Waste	wood (sawdust)	kg	6.90E-03
Waste	chemical waste (inert)	kg	1.51E-03

Waste	chemical waste	kg	1.44E-03
Waste	chemical waste (regulated)	kg	1.26E-03
Waste	waste in incineration	kg	1.01E-03
Waste	coal tailings	kg	8.45E-04
Waste	waste to recycling	kg	6.82E-04
Waste	Unspecified refuse	kg	4.63E-04
Waste	inorganic general	kg	8.30E-05
Waste	industrial waste	kg	2.67E-05
Waste	metals	kg	2.58E-05
Waste	construction waste	kg	1.96E-05
Waste	Municipal solid waste	kg	-5.79E-03
Water	dissolved solids	kg	2.76E-01
Water	water	kg	1.63E-01
Water	COD	kg	3.69E-02
Water	Cl-	kg	3.05E-02
Water	suspended solids	kg	2.15E-02
Water	sulphate	kg	1.15E-02
Water	BOD	kg	9.49E-03
Water	Na	kg	6.07E-03
Water	oil	kg	5.91E-03
Water	suspended substances	kg	4.86E-03
Water	Fe	kg	2.44E-03
Water	NH3 (as N)	kg	1.71E-03
Water	Cu	kg	1.05E-03
Water	nitrate	kg	8.36E-04
Water	other organics	kg	8.15E-04
Water	anorg. dissolved subst.	kg	7.52E-04
Water	N-tot	kg	7.37E-04
Water	Acid as H+	kg	5.61E-04
Water	sulphur/sulphide	kg	3.77E-04
Water	Mn	kg	3.18E-04
Water	B	kg	3.12E-04
Water	metallic ions	kg	3.06E-04
Water	phosphate	kg	2.85E-04
Water	sulphide	kg	2.70E-04
Water	Al	kg	2.46E-04
Water	NH3	kg	2.38E-04
Water	P-tot	kg	2.32E-04
Water	dissolved organics	kg	2.13E-04
Water	carbonate	kg	1.77E-04
Water	sulphates	kg	1.54E-04
Water	Cr	kg	1.38E-04
Water	Ni	kg	1.10E-04
Water	SiO2	kg	8.75E-05
Water	H2SO4	kg	7.80E-05
Water	calcium compounds	kg	7.56E-05
Water	acids (unspecified)	kg	7.55E-05
Water	CxHy	kg	7.39E-05
Water	Zn	kg	6.59E-05
Water	chlorate ion (ClO3-)	kg	5.16E-05
Water	organic carbon	kg	4.19E-05
Water	fluoride ions	kg	3.98E-05
Water	fats/oils	kg	3.81E-05
Water	TOC	kg	3.52E-05

Water	hydrocarbons (misc)	kg	1.87E-05
Water	H2	kg	1.42E-05
Water	Cd	kg	1.37E-05
Water	Sb	kg	1.07E-05
Water	V	kg	9.75E-06
Water	NH4+	kg	9.18E-06
Water	As	kg	8.63E-06
Water	Co	kg	8.52E-06
Water	detergent/oil	kg	7.54E-06
Water	K	kg	7.20E-06
Water	P	kg	6.88E-06
Water	phenol	kg	6.21E-06
Water	Mo	kg	6.08E-06
Water	Pb	kg	4.69E-06
Water	Ba	kg	3.87E-06
Water	nitrogen	kg	3.51E-06
Water	crude oil	kg	3.32E-06
Water	Cr (III)	kg	2.83E-06
Water	vinyl chloride	kg	2.15E-06
Water	Cr (VI)	kg	2.04E-06
Water	calcium ions	kg	1.69E-06
Water	P2O5	kg	1.59E-06
Water	CxHy aromatic	kg	1.22E-06
Water	phenols	kg	7.91E-07
Water	Dissolved chlorine	kg	6.45E-07
Water	Kjeldahl-N	kg	4.73E-07
Water	dichloroethane	kg	4.30E-07
Water	chromate	kg	2.79E-07
Water	cyanide	kg	2.70E-07
Water	AOX	kg	2.20E-07
Water	Mg	kg	2.15E-07
Water	organochloro pesticide	kg	2.15E-07
Water	toluene	kg	1.70E-07
Water	Ag	kg	1.55E-07
Water	Sn	kg	7.57E-08
Water	DOC	kg	5.75E-08
Water	PAH's	kg	1.86E-08
Water	Be	kg	1.61E-08
Water	Hg	kg	8.03E-09
Water	sodium dichromate	kg	2.05E-09
Water	CxHy chloro	kg	1.31E-09
Water	waste water (vol)	m3	8.90E-11
Water	herbicides	kg	1.05E-11
Water	pesticides	kg	5.33E-12