Comparative Life Cycle Assessment of Reusable vs. Disposable Textiles

Comparative Life Cycle Assessment of Reusable vs. Disposable Textiles

Prepared for

Textile Rental Services Association of America
188 Diagonal Road, Suite 200
Alexandria, VA 22314

Prepared by

John Jewell
PE International
344 Boylston Street, Third Floor
Boston, MA 02116

Randall Wentsel, Ph.D.
Exponent
1150 Connecticut Ave, NW, Suite 1100
Washington, DC 20036

August 7, 2014

Doc. no. 1200473.000 8193

Contents

List of Figures

List of Tables

Executive Summary

The Textile Rental Services Association of America (TRSA) commissioned Exponent and PE INTERNATIONAL, Inc., to compare selected reusable textiles against alternative disposable products. Environmental performance was evaluated for three types of textile products. Because the results of this comparison may be used for external communication, a critical review panel was engaged to ensure that the study meets the requirements of the ISO 14044 standard.

The scope of the study includes raw materials, production, use, and disposal of three pairs of reusable and disposable products: isolation gowns, wipers, and premium food-service napkins. Primary data were collected from TRSA member companies, and data gaps were filled using literature data and inventories from PE's GaBi 2012 database. Because many parameters in the life cycle of these products vary significantly, each system was modeled with worst-case assumptions, best-case assumptions, and in certain cases, mid-high and mid-low assumptions. Best-case assumptions are defined as those that lead to lowest environmental impacts, followed by mid-low, then mid-high and worst-case.

One area displaying significant variability was the use-phase washing process. To address this range, best-, mid-, and worst-case wash scenarios were created by ranking data providers within a product group by total energy demand (natural gas + electricity).

Results were evaluated for different environmental impact categories: acidification potential (AP), eutrophication potential (EP), global warming potential (GWP), ozone depletion potential (ODP), primary energy demand (PED), and smog formation potential (Smog). Across all categories considered, the disposables' impacts are mostly linked to raw materials and manufacturing. The reusable products' primary impacts are driven mainly by use-phase washing and manufacturing.

GWP impacts are shown below for isolation gowns, with burdens split across the different life-cycle stages (Figure ES-1). The other impacts show similar results for isolation gowns; reusables appear to have significantly less impact than their disposable alternatives.

Results for wipers are very similar and therefore are not displayed here; the worst-case reusables appear to perform significantly better than the best-case disposables, with the exception of EP, which is dominated by wastewater emissions during laundry.

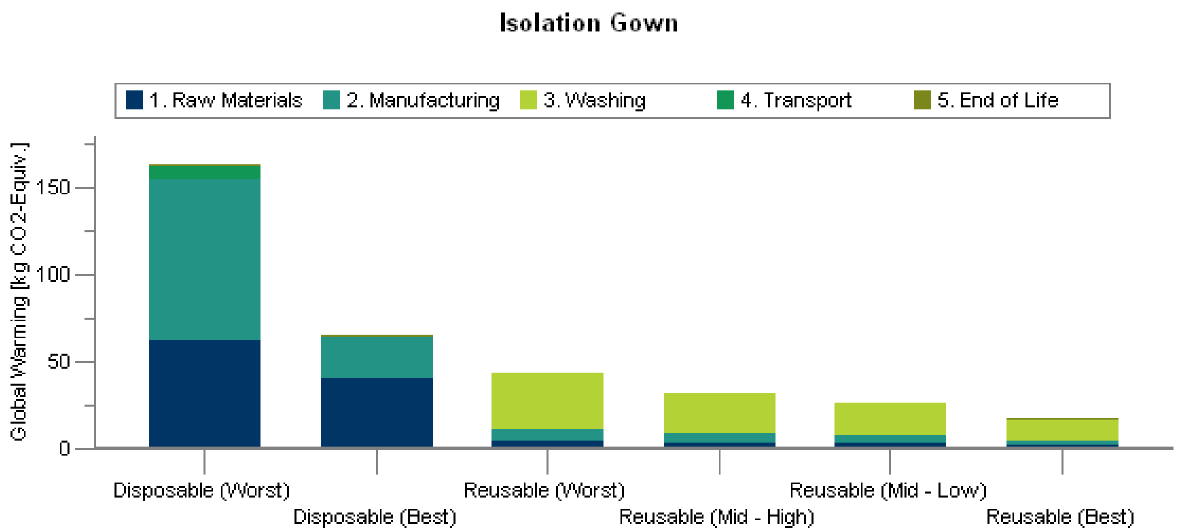

Figure ES-1-1. Isolation gown GWP breakdown

For napkins, the best- and worst-case scenarios overlap each other, depending on the assumptions and data used (Figure ES-2). For example, disposable napkins come in a range of weights and recycled content, which can cause the results to vary considerably. Additionally, literature suggests quite a range of environmental impacts for the manufacturing of paper. The comparison is evaluated based on scenarios wherein a consumer uses one napkin per meal. Finally, laundry energy demand was a key variable for reusable napkins.

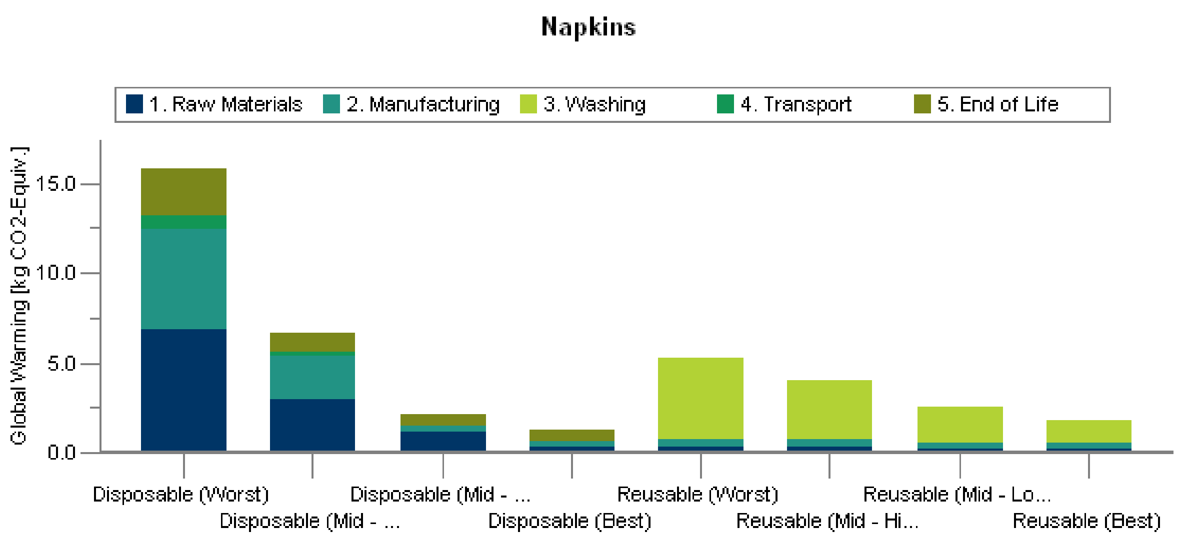

Figure ES-1-2. Napkin GWP breakdown

The worst-case and mid-high disposable napkin scenarios appear to have considerably higher impacts than all reusable scenarios. However, best-case and mid-low disposables are comparable with or slightly lower in impact than the worst-case and mid-high reusable scenarios.

Transportation and disposal are small contributors for all products and impacts considered.

In summary, the following conclusions appear to be reasonable:

- Reusable isolation gowns have clear environmental benefit compared to the analyzed disposable products, except in the case of ODP. The benefit comes from raw materials weight differences and nonwovens manufacturing.
- For wipers, the reusable products analyzed have a clear benefit for all impacts except EP. The benefit comes from raw-material differences. For EP, reusables have higher burdens, driven by wastewater emissions, which may not be relevant for all facilities.
- For napkins, worst and mid-high disposable scenarios appear to have higher burden than all reusable scenarios. The mid-low and best case disposable scenarios have similar but slightly lower impact than reusables. The product weight has the greatest influence on results, followed by recycled content, choice of high- or low-burden pulp, and use-phase washing variability.

1 Goal of the Study

The Textile Rental Services Association (TRSA) represents companies that provide and launder reusable textiles as a service to their clients. The goal of the study was to compare selected reusable textiles against alternative disposable products. Environmental performance was evaluated for the three case studies of reusable and disposable isolation gowns, wipers, and napkins. The results of this comparison may be used for external communication, so a critical review panel was engaged to ensure that the study meets the requirements of the ISO 14040/44 standards.

2 Scope of the Study

The following section describes the general scope of the project to achieve the stated goals. This includes identification of specific product systems to be assessed, their functional units, the system boundary, allocation procedures, cut-off criteria, among others.

2.1 Product Systems to be Studied

The three case studies evaluate reusable and disposable isolation gowns, wipers, and napkins. Isolation gowns are used in a healthcare setting to protect staff working in infectious conditions. Reusable and disposable gowns provide equivalent levels of protection, but the reusable gowns typically last for 64 washes. Wipers are used in industrial settings to clean oil, grease, and solvents off of equipment. Reusable wipers typically last for 12 washes before they begin to break down. Napkins are used in dining and hospitality to prevent stains and clean spills. Reusable napkins typically last at least 100 washings.

2.2 Functional Unit and Reference Flows

TSRA desires to compare the environmental performance of the reusable textile products to that of disposal products; therefore, the functional unit compares products on the basis of 100 use cases. To provide a fair comparison, the reusables and disposable alternatives must perform the same function, so the reference flows listed below were chosen (Table 2-1). Because the number of lifetime uses is a variable quantity, the number of reusable products needed to provide 100 uses varies from the best-case to the worst-case scenario. The masses shown represent the total weight of material needed to cover the range of best- and worst-case assumptions.

Table 2-1. Reference flows

	Isolation Gown	Wiper	Napkin
Reusable	1.02–2.04 PET gowns [0.313–0.739 kg]	8.33 cotton towels [0.227–0.265 kg]	1 PET napkin [0.032–0.051 kg]
Disposable	100 PP gowns [14.5 kg–22.2 kg]	100 pulp & PET towels [0.98 kg]	100 premium paper napkins [0.57–2.35 kg]

The assumed lifetime uses of each product is an important factor to the overall comparison, because manufacturing impacts are spread over the number of uses. Isolation gown lifetime comes from a 1999 TRSA Textile Life Survey of healthcare barrier gowns. Based on 4 years of data, the researchers found that the number of uses had a range of 98.08 (highest), 64.29 (median), and 49.13 (lowest). Wiper lifetime comes from a 1997 study "Environmental Assessment of Shop Towel Usage in the Automotive and Printing Industries," by the National Risk Management Research Laboratory in the Office of Research and Development. The study reported that woven towels have approximately 12 cycles of shop use and laundering at industrial laundries. These ranges are reflected in best-, mid-, and worst-case scenarios for each product. Napkin life data comes from the University of Kentucky Textile Lab testing document. Based on standard ASTM testing procedures, they found that napkins still perform after 100 uses. We assumed that napkins will be used until they fail; the University of Kentucky testing has shown that they will last at least 100 uses, so that is the lifetime modeled in our study.

2.3 System Boundaries

The scope of the study includes production, use, and disposal of three pairs of reusable and disposable products: isolation gowns, wipers, and premium food-service napkins. The analysis includes raw material production through manufacturing, transport, use, and final disposal. The geographic scope of the project is the United States.

Table 2-2 summarizes major components being considered for inclusion and exclusion from the study and has been shaped by the need to accurately reflect the environmental burden associated with the functional unit. While excluded parameters, such as packaging, may provide refinements to the LCA, it was determined not to use parameters that are judged to have minor impacts on the results of the LCA.

Table 2-2. System boundaries

Included	Excluded
✓ Raw materials production (forestry, chemicals, etc.)	× Construction of capital equipment
✓ Use of auxiliary materials, water, and energy during manufacturing, converting, and use	× Maintenance and operation of support equipment
✓ Emissions to air, water, and soil during manufacturing, converting, and use	× Human labor and employee commute
✓ Transport of raw materials and finished products	× Overhead (heating, lighting, warehousing) of manufacturing facilities
✓ Disposal	× Internal transportation (within a manufacturing facility)
	× Packaging of products

2.3.1 Time Coverage

Primary data collected from TRSA member companies represent the year 2012. Secondary data on product composition and manufacturing are taken from a range of sources between 1994 and 2013. Additional data necessary to model material production, energy use, etc., were adopted from PE's GaBi 2012 database and are described in further detail in Chapter 3.

2.3.2 Technology Coverage

Data on reusables' material composition and manufacturing are primary data from TRSA member companies, supplemented with secondary data from literature and the PE database. Most disposables' data come from secondary sources. In some cases, manufacturing details for a given technology are unknown, so proxy data are used to represent best- and worst-case scenarios. Table 3-2 gives more detail on the sources for the data used.

2.3.3 Geographic Coverage

Data collected are representative of the United States, with the exceptions noted in Table 3-2.

2.4 Allocation

2.4.1 Multi-Output Allocation

Reusable wipers were made from scraps generated in another product system, so no burden has been assigned to that product's first life. Allocation was used in the GaBi background data, as described below.

Allocation of upstream data (energy and materials):

- For all refinery products, allocation is conducted by mass and net calorific value. The manufacturing route of every refinery product is modeled, so the effort expended in production of these products is calculated specifically. Two allocation rules are applied:
  - 1. The raw material (crude oil) consumption of the respective stages, which is necessary for the production of a product or an intermediate product, is allocated by energy (mass of the product × calorific value of the product)
  - 2. The energy consumption (thermal energy, steam, electricity) of a process (e.g., atmospheric distillation) being required by a product or an intermediate product, are charged on the product according to the share of the throughput of the stage (mass allocation).
- Materials and chemicals needed during manufacturing are modeled using the allocation rule most suitable for the respective product. For further information on a specific product, see http://documentation.gabi-software.com/.

2.4.2 End-of-Life Allocation

In cases where the materials are sent to landfills, the appropriate product-specific share of the total EoL scrap is linked to a parameterized inventory that accounts for waste composition, regional leakage rates, landfill gas capture, and utilization rates (flaring vs. power production). A credit is assigned for power output using the regional grid mix.

TRSA and its members agree that products should be assumed to go to a landfill at their end of life. Although incineration may be a possible path, the authors have decided to simply model all waste in a landfill.

2.5 Cut-Off Criteria

No cut-off criteria were applied in this study. All reported data were incorporated and modeled using best available LCI data. For use of proxy data, see Chapter 2.9.

2.6 Selection of LCIA Method and Types of Impacts

A set of impact assessment categories and other metrics considered to be of high relevance to the goals of the project is shown in

Table 2-3 and Table 2-4. The U.S. Environmental Protection Agency's (EPA's) TRACI 2.0 method was selected, because literature data for the production of virgin and recycled paper reported impacts in TRACI 2.0.

Global warming potential (GWP) and primary energy demand (PED) were chosen because of their relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be among the most pressing environmental issues of our times.

Eutrophication potential (EP), acidification potential (AP), and smog creation potential (Smog) were chosen, because they are closely connected to air, soil, and water quality, and they capture the environmental burden associated with commonly regulated emissions such as NO_x, SO_2, VOCs, and others.

Ozone depletion potential (ODP) was chosen because of its high political relevance, which eventually led to the worldwide ban of ozone-depleting substances. Current exceptions to this ban include the application of ozone-depleting chemicals in nuclear power production. In addition, the slash-and-burn cultivation of field crops is known to result in relevant emissions of ozone-depleting substances. The indicator is therefore included for reasons of completeness and to be able to gauge the relevance of these emissions in comparison to other impacts.

Table 2-3. TRACI impact assessment descriptions

Impact Category	Description	Unit	Reference
Acidification potential (AP)	A measure of emissions that cause acidifying effects to the environment. The acidification potential is assigned by relating the existing S-, N-, and halogen atoms to the molecular weight.	kg SO_2 equivalent	(Bare 2011; U.S. EPA 2012)
Eutrophication potential (EP)	A measure of emissions that cause nutrifying effects to the environment. The eutrophication potential is a stoichiometric procedure, which identifies the equivalence between N and P for both terrestrial and aquatic systems	kg Nitrogen equivalent	(Bare 2011; U.S. EPA 2012)
Global warming potential (GWP)	A measure of greenhouse gas emissions, such as CO2 and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, magnifying the natural greenhouse effect.	kg CO_2 equivalent	(Bare 2011; U.S. EPA 2012)
Ozone depletion potential (ODP)	A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone to leads to higher levels of UVB ultraviolet rays.	kg CFC-11 equivalent	(Bare 2011; U.S. EPA 2012)
Smog creation potential (Smog)	A measure of emissions of precursors that contribute to low level smog, produced by the reaction of nitrogen oxides and VOC's under the influence of UV light.	kg O_3 equivalent	(Bare 2011; U.S. EPA 2012)

Table 2-4. Other environmental indicators

Indicator	Description	Unit	Reference
Primary energy demand (PED)	A measure of the total amount of fossil resources extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g., petroleum, natural gas, etc.).	MJ (surplus)	(Bare 2011; U.S. EPA 2012)

It shall be noted that the above impact categories represent impact *potentials*; i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the reported emissions represent only that fraction of the total environmental load that corresponds to the functional unit.

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

2.7 Interpretation to be Used

The study applies normalization to statistical yearly U.S. emissions as a means to establish the order of magnitude in which each product system would contribute to the average environmental burden of a given year. This is a comparative assertion to be disclosed to third parties, so no grouping or quantitative cross-category weighting has been applied. Instead, each impact is discussed in isolation, without reference to other impact categories, before final conclusions and recommendations are made.

Note that, in situations where no product outperforms all of its alternatives in each of the impact categories, some implicit form of cross-category evaluation is inevitable to draw conclusions regarding the environmental superiority of one product over the other. ISO 14044 rules out the use of quantitative weighting factors in comparative assertions to be disclosed to the public, so this evaluation will take place qualitatively, and the defensibility of the results therefore depends on the authors' expertise and ability to convey the underlying line of reasoning that led to the final conclusion.

2.8 Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regard to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of high *precision*, followed by calculated and estimated data.
- *Completeness* is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. As stated in Section 2.4.2, no cut-off criteria were applied.
- *Consistency* refers to modeling choices and data sources. The goal is to ensure that differences in results occur due to actual differences between product systems, and not due to inconsistencies in modeling choices, data sources, emission factors, or other factors.
- *Representativeness* expresses the degree to which the data match the geographic, temporal, and technological requirements defined in the study's goal and scope.

An evaluation of the data quality with regard to these requirements is provided in the interpretation chapter of this report.

2.9 Assumptions and Limitations

A number of assumptions are used where adequate data were not available from either primary or secondary sources—in most cases, a range of values was used to signify "best-case" and "worst-case" scenarios. Notable assumptions and limitations are described below, and a full list of data used is included in Chapter 3 below.

- Manufacturing of disposable isolation gowns is modeled based on data for surgical gowns (worst case) or spunbond nonwoven fabric (best case).
- Initial transportation distance from manufacturing to customer was assumed to be 250 miles (worst case) or 100 miles (best case) for all disposable and reusable product scenarios. Although some of these products typically may be manufactured overseas, this comparison focuses on North American boundary conditions. The environmental implications of this choice are small, because ocean transport has considerably lower impact than trucking. For example, the global warming effect of transporting a good 100 miles by truck is roughly equivalent to shipping that same item 3,300 miles by ship.
- Cotton scraps used in reusable wiper manufacturing were assumed to carry no fraction of the burden of virgin cotton fiber. The scraps are generated as internal waste (part of another product system), rather than purchased on the scrap market, so they were given no environmental burden.
- Consumers were assumed to use one premium disposable napkin or one cloth reusable napkin per meal regardless of product weight. Disposable napkin weights were taken from publically available information on premium, two-ply napkins with varying weights and levels of recycled content.
- Without data on the weights and manufacturing of elastomeric cuffs and other isolation gown trim, they have been excluded from the study.

Despite uncertainty around which scenarios are more prevalent in real-life situations, results are interpreted for all scenarios to provide additional confidence in the conclusions.

2.10 Software and Database

The LCA model was created using the GaBi 6 software system for life-cycle engineering, developed by PE INTERNATIONAL AG. The GaBi 2012 LCI database provides the life-cycle inventory data for the background system, as shown in Chapter 3.

2.11 Critical Review

TRSA intends to disclose the LCA results to the public in external or business-to-customer communications; therefore, ISO14040 requires third-party review by a panel of three independent experts. The reviewers were:

- Dr. Arpad Horvath, Consultant, Berkeley, California (panel chair)
- Jim Mellentine, Sustainable Solutions
- Dr. Christopher Pastore, Philadelphia University.

3 Life-Cycle Inventory (LCI) Analysis

3.1 Data Collection

3.1.1 Data Collection and Quality Assessment Procedure

All primary data were collected by email, with the respective data providers in the participating companies using pre-formatted spreadsheets. Data were cross-checked for completeness and plausibility using mass balance, stoichiometry, and benchmarking. If gaps, outliers, or other inconsistencies occurred, PE INTERNATIONAL engaged with the data provider to resolve any open issues.

The project was further subjected to a comprehensive quality assurance process at every major milestone in the project, to analyze and ensure model integrity, data accounting, and consistency with the goal and scope.

Product composition and manufacturing details were collected from TRSA member companies when possible, but their main role was to provide washing details. Data on washing energy and water came from a Clean Green survey of 70 TRSA member companies. Chemistry and emissions data were reported by 21 sites.

Many parameters in the life cycle of these products had significant variability, so each system was modeled with worst-case assumptions, best-case assumptions, and in certain cases, mid-level or mid-high and mid-low assumptions. In general, best-case assumptions are defined as those that lead to lower environmental impacts, and worst-case assumptions lead to higher environmental impacts. The mid-high scenario has higher impacts than mid-low, which has higher impacts than the best case. By using these scenarios to model the disposable and reusable product systems, uncertainty due to assumptions and data variability was accounted for, which allows conclusions to be drawn with more confidence.

3.1.2 Fuels and Energy — Background Data

National and regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 6 database 2012. Table 3-1 shows the most relevant LCI data sets used in modeling the product systems.

Table 3-1. Key energy datasets used in inventory analysis

Energy	Data Set Name	Primary Source	Year	Geography
Electricity	Electricity grid mix	PE	2009	US
Technical heat	Thermal energy from natural gas	PE	2009	US
Diesel for trucking	Diesel mix at refinery	PE	2009	US

Documentation for all generic data sets can be found at http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/.

3.1.3 Raw Materials and Processes—Background Data

Data for up- and downstream raw materials and unit processes were obtained from the GaBi 6 database 2012. Table 3-2 shows the most relevant LCI data sets used in modeling the product systems. Documentation for all generic datasets can be found at http://www.gabi-software.com/support/gabi/gabi-6-lci-documentation/.

Note that, in some cases, a material or process is used in multiple product systems. For ease of display, the Reusable scenarios are abbreviated (R), and Disposable scenarios are abbreviated (D).

Table 3-2. Key material and process data sets used in inventory analysis

Product System(s)	Material/Process	Data Set Name	Primary Source	Year	Geography
Gown (R) Napkin (R) Wiper (D)	PET fiber	Polyethylene terephthalate fibers (PET)	PE	2011	US
Gown (D)	PP fiber	Polypropylene fibers (PP)	PE	2011	US
Gown (R) Wiper (R)	Fabric manufacturing	Woven cotton fabric manufacturing	Cotton Inc.	2011	Global
Napkin (D) Wiper (D)	Pulp	Virgin Pulp	Environ	2013	North America
		Deinked Pulp	Environ	2013	
Napkin (D) Wiper (D)	Tissue making	Tissue making	EC Joint Research Center	2011	EU
Wiper (R)	Recycled cotton	n/a	n/a	n/a	n/a

Data for woven cotton fabric manufacturing comes from a high-quality LCI recently published by Cotton, Inc. The global average data set is based on data from China, India, Latin America, and Turkey, representing 66% of global production. The following processes are used to create woven fabric from fiber and give it desired properties such as color, texture, and finishes: beam / slash / dry, weaving, continuous dyeing, finishing, and sanforizing. System boundaries are shown in Figure 3-1. Energy, chemicals, and transport are included. Manufacturing synthetics is assumed to be comparable to cotton, so this LCI is an appropriate proxy.

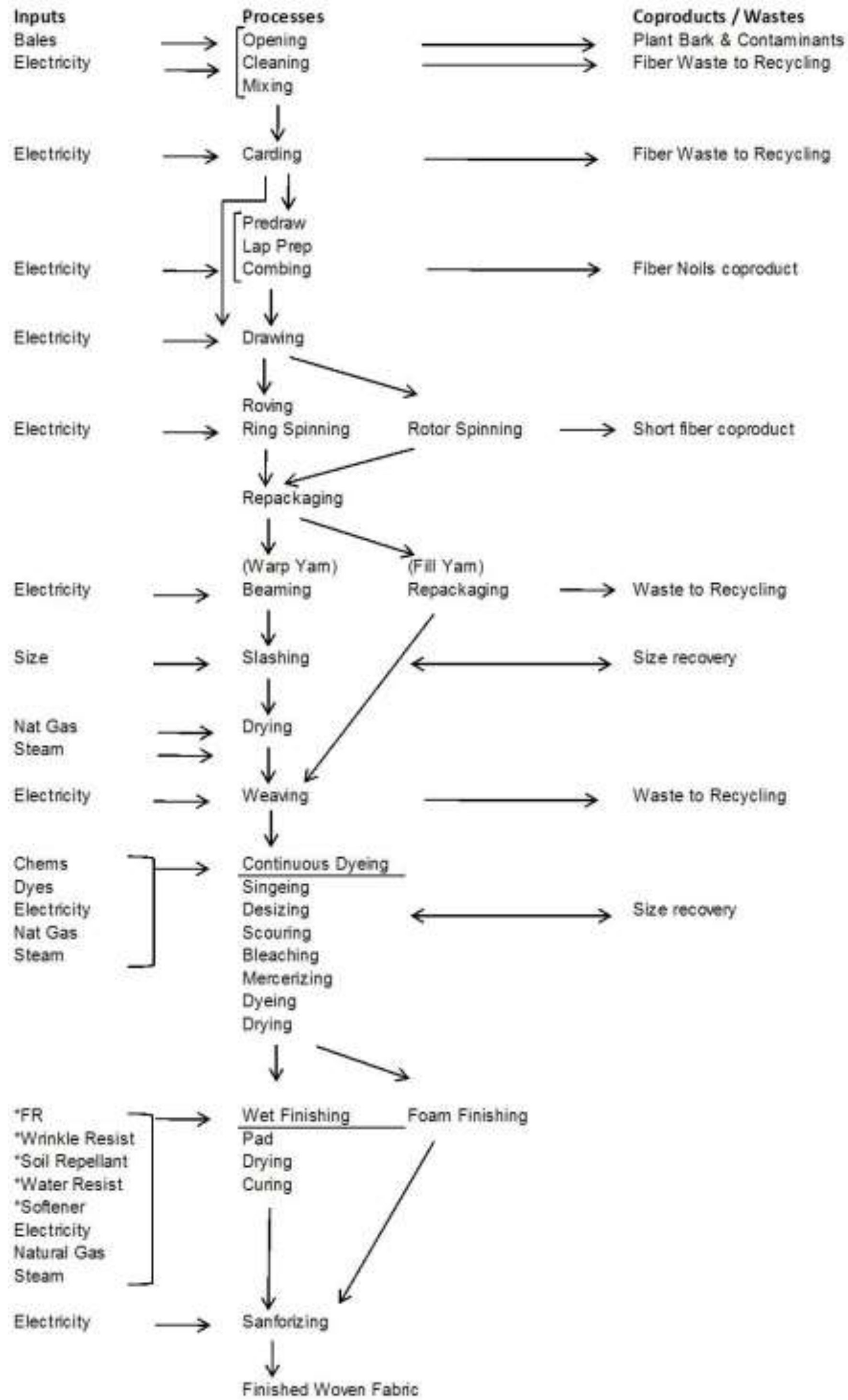

Figure 3-1. System boundaries of fabric manufacturing LCI

3.1.4 Transportation

The GaBi data sets for road transport and fuels were used to model transportation. Truck transportation within the United States was modeled using the GaBi 6 US truck transportation data sets. The vehicle types, fuel usage, and emissions for these transportation processes were developed using a GaBi model based on the U.S. Census Bureau Vehicle Inventory and Use Survey (2002) and U.S. EPA emissions standards for heavy trucks in 2007. The 2002 VIUS survey is the latest available survey describing truck-fleet fuel consumption and utilization ratios in the U.S., and the 2007 EPA emissions standards are considered to be the most appropriate data available for describing current U.S. truck emissions.

3.1.5 Emissions to Air, Water, and Soil

Emission data for all upstream materials, electricity, and energy carriers were obtained from the GaBi 6 database 2012. The emissions (CO_2, NO_x, SO_2, etc.) due to the use of electricity and combustion of fuels are accounted for with the use of the database processes.

Primary data on water emissions from laundering were obtained from selected laundry facilities. Lacking enough consistent information for an industry average, best- and worst-case emissions data from selected laundries were used.

Emissions associated with transportation were determined by capturing the logistical operations of involved companies (data collected from the companies for the reference year). Energy use and the associated emissions were calculated using pre-configured transportation models from the GaBi 6 database 2012, adapted with transportation supplier data (specific fuel economy, specific emissions, etc.).

3.2 Isolation Gown System

3.2.1 Overview of Life Cycle

Isolation gowns are used in the healthcare industry to protect staff working in infectious conditions. Reusable gowns are made from woven polyester fabric. Disposable gowns are made from nonwoven polypropylene fabric. Both products are manufactured, then delivered by truck. Reusable products are picked up from TRSA’s clients, then laundered and returned. After their useful lives, both products are disposed of in a standard landfill.

Isolation gown lifetime comes from a 1999 TRSA Textile Life Survey of healthcare barrier gowns. Based on 4 years of data, they found that the number of uses ranged from 98.08 (highest), to 64.29 (median), to 49.13 (lowest). To achieve the reference flow of 100 uses, the reusable gowns must be produced 1.02, 1.56, and 2.04 times, respectively.

Data points used in each scenario are summarized in Table 3-3.

3.2.2 Raw Materials

Primary data were collected on raw materials from a TRSA member, in the case of reusables. The disposable gown material type and composition were taken from literature (McIlvane, 2009).

3.2.3 Manufacturing

For the reusable gown, a global average data set for woven fabric manufacturing based on data from (Cotton, Inc., 2012) was used. This data set includes fiber preparation and the processes to give it desired properties such as color, texture, and finishes.

For disposable gown manufacture, we considered the production of a non-woven polypropylene gown. Our worst-case scenario included electricity (5.16 MJ/gown) for surgical gown manufacturing (McIlvane, 2009). Our best-case scenario included electricity (1.31 MJ/gown) for spunbond nonwoven production (Malkan, 1994). The spunbond nonwoven energy data for this best-case scenario was also used for reusable wipers.

Primary data on manufacturing waste were used for all disposables and reusables scenarios (5.7% and 5.0%, respectively). All inputs upstream of waste are increased to account for these losses.

Note that isolation gowns likely have elastomeric cuffs, pockets, and other trim. Without data on the weights and manufacturing of these trim, they have been excluded from the study.

3.2.4 Transport

For the transport of raw materials to manufacturing facilities, an assumed transportation distance of 100 miles by a Class 5 truck is included. For the first delivery of finished products to customers, no transportation data were collected. Lacking data, we assumed either 100 miles (best case) or 250 miles (worst case) for both reusables and disposables.

Because reusables are delivered to clients and then picked up for laundering, we collected data on average delivery and pickup routes among TRSA members. The average total distance for a route was 110 miles for wipers and 70 miles for gowns and napkins. Textiles are not very dense, so delivery vans will meet their volumetric capacity before approaching their weight capacity. Truck emissions are calculated based on the payload weight as a fraction of total capacity, known as the truck’s utilization, so primary data on laundry density and truck volume were needed. The primary data from TRSA member companies had considerable variability, so a range of utilization factors was used (worst, 0.14; mid-high, 0.24; mid-low, 0.4; and best, 0.61).

3.2.5 Use

Primary data were collected from the TRSA to quantify the energy, water, and chemicals needed for laundering reusable textiles. Laundry data were provided for general industrial-scale washing, as well as for gowns alone. The following table shows inputs and outputs of the laundry process for each scenario. Use-phase scenarios are divided into worst, mid-high, mid-low, and best case. In cases where detail was unavailable for all the inputs and outputs (e.g., wash chemistry), we applied values averaged from all other respondents.

A summary of inputs and outputs from the washing process is presented in Table 3-4.

The wash chemistry is made from a mixture of chemicals (Figure 3-2). We collected primary data from three member companies on the composition of this mixture. LCI data for these chemicals were taken from the GaBi 2012 database.

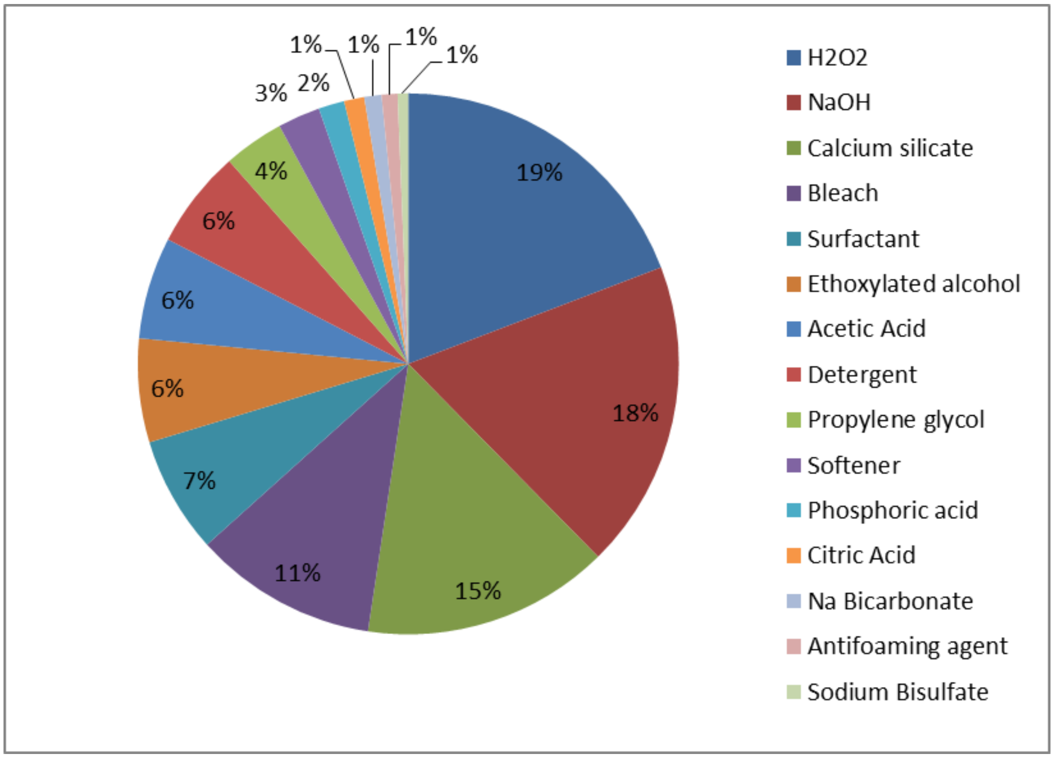

Figure 3-2. Isolation gown wash chemistry (in %)

3.2.6 End of Life

At the end of their useful life, we assume that the products are trucked 20 miles to a standard landfill. PE's GaBi database includes the fuel and emissions for landfill earth movers, leachate to water, and emissions air. As described in Section 2.4.2, the capture and flaring of landfill gas is also included based on prevalence across U.S. landfills.

A summary of data points used in each scenario is given below. Text in **bold** denotes parameters that vary across the different scenarios.

Table 3-3. Isolation gown parameters

Gown	Scenario	Raw Materials	Manufacturing	Transport	Use	End of Life
Disposables	Worst Case	**7.83** oz. PP produced 100 times	**Surgical gown** manuf. energy (**5.16 mj**)	**250 mi** delivery, **0.14** utilization	n/a	standard landfill
	Best Case	**5.12** oz. PP produced 100 times	**Spunbond nonwoven** energy (**1.31 mj**)	**100 mi** delivery, **0.61** utilization	n/a	standard landfill
Reusables	Worst Case	**12.8** oz. PET replaced 2.04 times	Average weaving, **0.22 mj** cut & sew	70 mi pickup / delivery, **0.14** utilization	**worst** washing	standard landfill
	Mid – High	**12.8** oz. PET replaced 1.56 times	Average weaving, **0.22 mj** cut & sew	70 mi pickup / delivery, **0.24** utilization	**mid-high** washing	standard landfill
	Mid – Low	**10.82** oz. PET replaced 1.56 times	Average weaving, **0.007 mj** cut & sew	70 mi pickup / delivery, **0.40** utilization	**mid-low** washing	standard landfill
	Best Case	**10.82** oz. PET replaced 1.02 times	Average weaving, **0.007 mj** cut & sew	70 mi pickup / delivery, **0.61** utilization	**best** washing	standard landfill

A summary of inputs and outputs from the washing process is given below.

Table 3-4. Isolation gown washing

Gown		Worst	Mid-High	Mid-Low	Best
Electricity	[Btu / lb laundry]	614.16	375.32	375.32	272.96
Natural Gas	[Btu / lb laundry]	3471.00	2185.00	2185.00	1638.00
Water	[gal / lb laundry]	2.23	1.25	1.25	0.78
Wash Chemistry	[lbs / lb laundry]	0.01	0.01	0.00	0.01
Waste Water	[gal / lb laundry]	1.60	1.58	1.45	1.48

3.3 Wipers

3.3.1 Overview of Life Cycle

Wipers are used in industrial settings to clean oil, grease, and solvents off equipment. Reusable wipers are made from recycled cotton fibers. Disposable wipers are made from nonwoven pulp and polyester fabric. Both products are manufactured and then are assumed to be delivered by truck. Reusable products are picked up from TRSA’s clients using a Class 5 truck (step van), then laundered and returned. After their useful lives, both products are disposed of in a standard landfill.

Wiper lifetime comes from a 1997 EPA study, "Environmental Assessment of Shop Towel Usage in the Automotive and Printing Industries," by the National Risk Management Research Laboratory in the Office of Research and Development. The study reported that woven towels have approximately 12 cycles of shop use and are laundered via water washing at industrial laundries.

A summary of data points used in each scenario is presented in Table 3-5.

3.3.2 Raw Materials

Primary data were collected on raw-material weights from TRSA members. The product is made primarily from cotton scraps that are reclaimed from the manufacturing site. Because the scraps aren't purchased from external sources, no burden from the virgin production of cotton is allocated to the material.

The disposable wiper material type and composition were taken from literature (Pullman, 1997). Data for kraft pulp production also came from literature (Joint Research Centre, 2012), but the source documented a significantly wide variation in the technologies used for kraft pulp making and subsequent tissue manufacturing. Ranges were provided to represent the current industry practice, so we built "high-impact" and "low-impact" versions of kraft pulp and tissue making for use in the model.

Some disposable wipers may also contain recycled content. A TRSA member who manufactures disposable wipers provided the information that wipers can contain as much as 40% post-consumer recycled material. He states that the recycled content likely comes from the paper rather than polyester. To consider this aspect, we took the formulation specified in literature (65% pulp / 35% PET) and assumed that the best-case wiper had 40% recycled pulp / 15% virgin pulp / 35% PET. The worst-case scenario was made with 65% virgin pulp / 35% PET.

3.3.3 Manufacturing

Lacking primary data on the manufacturing of reusables, we assumed energy demand to match the generic spunbond nonwoven process (0.286 MJ/towel). The spunbond nonwoven energy data for wipers were the best data available and were also used for disposable gowns. Primary data came from TRSA member companies on water (0.02 L/towel), as well as waste (8% and 10% for best and worst cases, respectively). All inputs upstream of waste are increased to account for these losses.

Disposable wiper manufacturing energy and water use were taken from literature (Pullman, 1997).

3.3.4 Transport

For the transport of the raw materials to manufacturing facilities, an assumed transportation distance of 100 miles by truck is included. For the first delivery of finished products to customers, no transportation data were collected. Lacking data, we assumed either 100 miles (best case) or 250 miles (worst case) for both reusables and disposables.

Reusables are delivered to clients, then picked up for laundering, so we collected data on average delivery / pickup routes among TRSA members. The average total distance for a route was 110 miles for wipers and 70 miles for gowns and napkins. Because textiles are not very dense, delivery vans will meet their volumetric capacity before approaching their weight capacity. Truck emissions are calculated based on the payload weight as a fraction of total capacity, known as the truck's utilization, so primary data on laundry density and truck volume were needed. The primary data from TRSA member companies had considerable variability, so a range of utilization factors was used (worst, 0.14; mid-high, 0.24; mid-low, 0.4; and best, 0.61).

3.3.5 Use

Primary data were collected from the TRSA to quantify the energy, water, and chemicals needed for laundering reusable textiles. Laundry data were provided for general industrial-scale washing, as well as for wipers alone. The following table shows inputs and outputs of the laundry process for each scenario. Use-phase scenarios are divided into worst, mid-high, mid-low, and best case. In cases where detail was unavailable for all the inputs and outputs (e.g., wash chemistry), we applied values averaged from all other respondents.

A summary of inputs and outputs from the washing process is presented in
Table 3-6.
The wash chemistry is made from a mixture of chemicals (Figure 3-3). We collected primary data from three member companies on the composition of this mixture. LCI data for these chemicals come from the GaBi 2012 database.

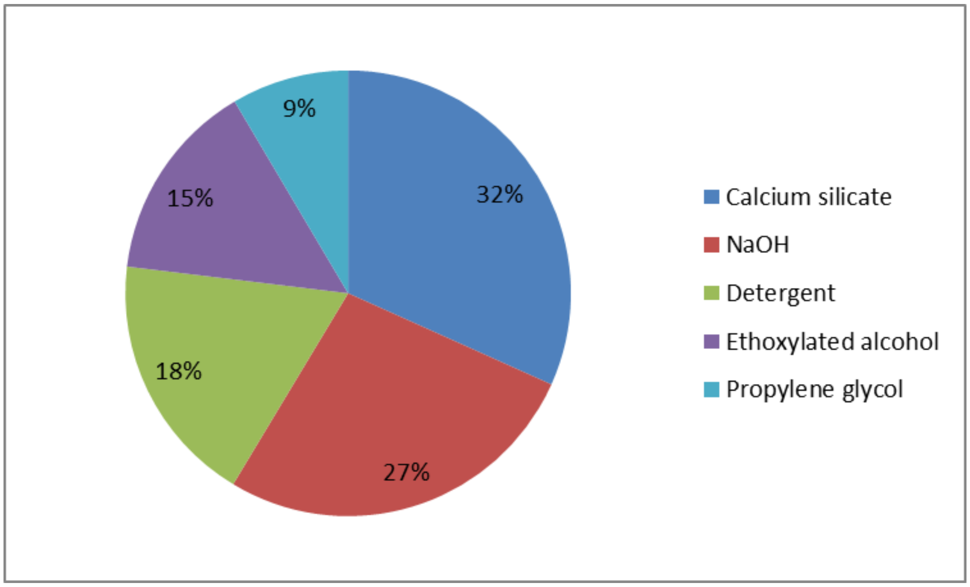

Figure 3-3. Wiper wash chemistry (in %)

3.3.6 End of Life

At the end of their useful life (one use for disposables or 12 uses for reusables), the products are trucked 20 miles to a standard landfill. PE's GaBi database includes the fuel and emissions for landfill earth movers, leachate to water, and emissions to air. As described in Section 2.4.2, the capture and flaring of landfill gas is also included, based on prevalence across U.S. landfills.

The parameters used in each scenario are given below. Text in **bold** denotes parameters that vary across the different scenarios.

Table 3-5. Wiper parameters

Wiper	Scenario	Raw Materials	Manufacturing	Transport	Use	End of Life
Disposables	Worst Case	**0.35 oz virgin** Pulp (**high impact**) & PET produced 100 times	**wiper manufacturing** (literature)	**250 mi** delivery, **0.14** utilization	n/a	standard landfill
	Best Case	**0.35 oz recycled and virgin** Pulp (**low impact**) & PET produced 100 times	**wiper manufacturing** (literature)	**100 mi** delivery, **0.61** utilization	n/a	standard landfill
Reusables	Worst Case	**1.12 oz** scraps replaced 8.33 times	**spunbond nonwoven process**	110 mi pickup / delivery, **0.14** utilization	**worst** washing	standard landfill
	Mid - High	**1.02 oz** scraps replaced 8.33 times	**spunbond nonwoven process**	110 mi pickup / delivery, **0.24** utilization	**mid-high** washing	standard landfill
	Mid - Low	**0.99 oz** scraps replaced 8.33 times	**wiper manufacturing** (literature)	110 mi pickup / delivery, **0.40** utilization	**mid-low** washing	standard landfill
	Best Case	**0.96 oz** scraps replaced 8.33 times	**wiper manufacturing** (literature)	110 mi pickup / delivery, **0.61** utilization	**best** washing	standard landfill

Inputs and outputs from the washing process are given below.

Table 3-6. Wiper washing

Wiper		Worst	Mid-High	Mid-Low	Best
Electricity	[Btu / lb laundry]	614.16	341.20	341.20	204.72
Natural gas	[Btu / lb laundry]	3542.00	2024.00	2024.00	1159.00
Water	[gal / lb laundry]	3.84	2.90	1.45	0.88
Wash chemistry	[lbs / lb laundry]	0.01	0.04	0.05	0.03
Waste water	[gal / lb laundry]	3.57	3.16	1.45	0.79
Sludge	[lbs / lb laundry]	0.00	3.50	1.70	1.60
Grease	[mg / L wastewater]	750.00	750.00	750.00	750.00
Solvents	[mg / L wastewater]	50.00	50.00	50.00	50.00
Heavy metals	[mg / L wastewater]	6.00	6.00	6.00	6.00
Biological oxygen demand	[mg / L wastewater]	750.00	750.00	750.00	750.00
Total suspended solids	[mg / L wastewater]	750.00	750.00	750.00	750.00
Sodium hydroxide	[mg / L wastewater]	0.21	0.21	0.21	0.21
Detergent	[mg / L wastewater]	0.10	0.10	0.10	0.10
Softener/souring agent	[mg / L wastewater]	0.13	0.13	0.13	0.13

3.4 Napkins

3.4.1 Overview of Life Cycle

Napkins are used in dining and hospitality to prevent stains and clean spills. We are evaluating reusable napkins made from polyester. Disposable napkins are made from paper tissue derived from virgin and recycled pulp. Both products are manufactured then delivered by truck. Reusable products are picked up from TRSA's clients, then laundered and returned. After their useful lives, both products are disposed in a standard landfill.

Napkin life data come from the University of Kentucky Textile Lab testing document (Meredith, 2011). Based on standard ASTM testing procedures, they found that napkins still perform after 100 uses.

Parameters used in each scenario are presented in Table 3-7.

3.4.2 Raw Materials

Primary data were collected on raw material weights from TRSA members in the case of reusables.

The disposable-napkin data for paper production came from literature (Environ, 2012) (Joint Research Centre, 2012). The Environ report included some discussion about the potential range in impacts for pulp making, depending on variations in pulp production energy, pulp production fuel mix, and assumptions regarding recycling allocation. Despite the range of possible impacts that pulp could have, we reduced the number of disposable napkin scenarios by considering only the baseline pulp making for use in this study. Further justification for this decision is included in Section 4.2.3. The Environ report describes only the production of pulp-making, but not paper making, so data from the Joint Research Centre was used for paper making.

The Joint Research Centre study documented a significantly wide variation in the technologies used for tissue manufacturing. Because ranges were presented to represent the current industry practice, we built "high-impact" and "low-impact" versions of tissue making for use in the model.

Lacking industry data describing the range of products available on the market, disposable-napkin weights were taken from publically available information on premium, two-ply napkins with varying weights and levels of recycled content. The worst-case scenarios are represented by a 23.5-gram 100% virgin napkin made by Dunicel, as reported in an existing LCA (IVL, 2011). The mid-high napkin was represented by the Georgia Pacific Preference napkin (GP Preference, 2013), a 5.4-gram 30% recycled product. The mid-low napkin was represented by the Georgia Pacific Essentials napkin (GP Essentials, 2013), a 10.2-gram 100% virgin product. The best-case scenarios are represented by a 5.7-gram 100% recycled napkin made by Earth First (Earth First, 2013).

3.4.3 Manufacturing

For the reusable napkin, we used a global average data set from the PE database for woven fabric manufacturing. This data set includes fiber preparation and the processes to give it desired properties such as color, texture, and finishes. Energy and waste for cut-and-sew are also included in reusable napkin manufacturing. Primary data from two TRSA members showed considerable differences, so they were used as best (0.02 MJ/napkin) and worst cases (0.22 MJ/napkin).

The kraft pulp and tissue-making data from literature included manufacturing inputs and outputs relevant to disposable napkins.

3.4.4 Transport

For the transport of the raw materials to manufacturing facilities, an assumed transportation distance of 100 miles, by truck, is included. For the first delivery of finished products to customers, no transportation data were collected. Lacking data, we assumed either 100 miles (best case) or 250 miles (worst case) for both reusables and disposables.

Reusables are delivered to clients then picked up for laundering; therefore, we collected data on average delivery and pickup routes among TRSA members. The average total distance for a route was 110 miles for wipers and 70 miles for gowns and napkins. Because textiles are not very dense, delivery vans will meet their volumetric capacity before approaching their weight capacity. Truck emissions are calculated based on the payload weight as a fraction of total capacity, known as the truck's utilization, so primary data on laundry density and truck volume were needed. The primary data from TRSA member companies had considerable variability, so a range of utilization factors was used (worst, 0.14; mid-high, 0.24; mid-low, 0.4; and best: 0.61).

3.4.5 Use

Primary data were collected from the TRSA to quantify the energy, water, and chemicals needed for laundering reusable textiles. Laundry data were provided for general industrial-scale washing, as well as for napkins alone. The following table shows inputs and outputs of the laundry process for each scenario. Use-phase scenarios are divided into worst, mid-high, mid-low, and best case. In cases where detail was unavailable for all the inputs and outputs (e.g., wash chemistry), we applied values averaged from all other respondents.

Inputs and outputs from the washing process are presented in Table 3-8.

The wash mixture is made from a combination of chemicals (Figure 3-4). We collected primary data from three member companies on the composition of this mixture. LCI data for these chemicals come from the GaBi 2012 database.

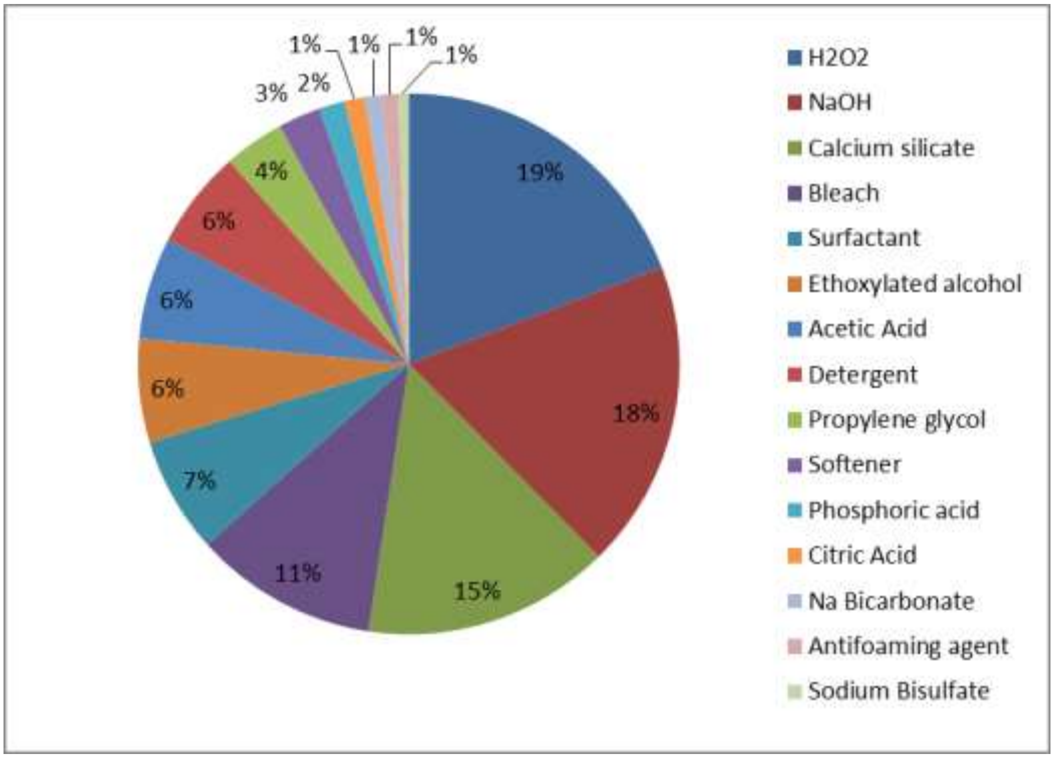

Figure 3-4. Napkin wash chemistry (in %)

3.4.6 End of Life

At the end of their useful life (one use for disposables or 100 uses for reusables), these napkins are trucked 20 miles to a standard landfill. PE's GaBi database includes the fuel and emissions for landfill earth movers, leachate to water, and emissions to air. As described in Section 2.4.2, the capture and flaring of landfill gas is also included based on prevalence across U.S. landfills.

The parameters used in each scenario are given below. Text in **bold** denotes parameters that vary across the different scenarios.

Table 3-7. Napkin parameters

Wiper	Scenario	Raw Materials	Manufacturing	Transport	Use	End of Life
Disposables	Worst Case	**23.5 g** paper produced 100 times	Virgin pulp + **High**-impact papermaking, **0**% recycled	**250 mi** delivery, **0.14** utilization	n/a	standard landfill
	Mid - High	**10.2 g** paper produced 100 **times**	Virgin pulp + **High**-impact papermaking, **0**% recycled	**250 mi** delivery, **0.24** utilization	n/a	standard landfill
	Mid - Low	**5.35 g** paper produced 100 times	Virgin pulp + **Low**-impact papermaking, **30**% recycled	**100 mi** delivery, **0.40** utilization	n/a	standard landfill
	Best Case	**5.66 g** paper produced 100 times	Recycled pulp + **Low**-impact papermaking, **100**% recycled	**100 mi** delivery, **0.61** utilization	n/a	standard landfill
Reusables	Worst Case	**50.8 g** PET used 100 times	**0.22 MJ/napkin, 1.5% waste**	**70 mi** delivery, **0.14** utilization	**worst** washing	standard landfill
	Mid - High	**50.8 g** PET used 100 times	**0.22 MJ/napkin, 1.5% waste**	**70 mi** delivery, **0.24** utilization	**mid-high** washing	standard landfill
	Mid - Low	**32.1 g** PET used 100 times	**0.02 MJ/napkin, 1.5% waste**	**70 mi** delivery, **0.40** utilization	**mid-low** washing	standard landfill
	Best Case	**32.1 g** PET used 100 times	**0.02 MJ/napkin, 1.5% waste**	**70 mi** delivery, **0.61** utilization	**best** washing	standard landfill

Inputs and outputs from the washing process are given below.

Table 3-8. Napkin washing

Wiper		Worst	Mid-High	Mid-Low	Best
Electricity	[Btu / lb laundry]	614.16	443.56	443.56	272.96
Natural gas	[Btu / lb laundry]	3471.00	2185.00	2185.00	1638.00
Water	[gal / lb laundry]	2.23	1.25	1.25	0.78
Wash chemistry	[lbs / lb laundry]	0.01	0.01	0.00	0.01
Waste water	[gal / lb laundry]	1.60	1.58	1.45	1.48
Sodium hydroxide	[mg / L wastewater]	**0.79**	0.79	0.79	0.79
Detergent	[mg / L wastewater]	**0.87**	0.87	0.87	0.87
Softener/souring agent	[mg / L wastewater]	**0.07**	0.07	0.07	0.07
Mildewcide	[mg / L wastewater]	**0.04**	0.04	0.04	0.04

3.5 Life-Cycle Inventory Analysis Results

ISO 14044 defines the Life Cycle Inventory Analysis Result as the "outcome of a life cycle inventory analysis that catalogues the flows crossing the system boundary and provides the starting point for life cycle impact assessment." The complete inventory comprises hundreds of flows, so the below table displays only a selection of flows, based on their relevance to the subsequent impact assessment, in order to provide a transparent link between the inventory and impact assessment results.

The complete inventory is available on request from the study authors.

Table 3-9. LCI results (kg of each material) for the isolation gown systems

Type	Flow	Disposable (Worst)	Disposable (Best)	Reusable (Worst)	Reusable (Mid–High)	Reusable (Mid–Low)	Reusable (Best)
Resources							
	Crude oil	17.74287	9.650646	1.620897	1.14735	0.894749	0.596018
	Hard coal	29.65383	9.002327	4.906118	3.603784	2.957338	1.907622
	Lignite	6.449989	3.03078	1.361297	0.990311	0.814741	0.531038
	Natural gas	35.16405	19.96574	10.02809	7.164633	5.955812	3.923817
	Uranium	0.00078	0.000253	9.36E-05	6.78E-05	5.52E-05	3.54E-05
Emissions to Air							
	Carbon dioxide	153.6933	61.15521	41.24934	29.6622	24.47632	15.99842
	Carbon monoxide	0.101645	0.039194	0.022535	0.015831	0.012	0.008239
	Nitrogen dioxide	2.12E-05	8.86E-06	1.92E-05	1.29E-05	1.05E-05	6.67E-06
	Nitrogen oxides	0.000174	8.28E-05	0.000175	0.00011	8.79E-05	5.61E-05
	Sulphur hexafluoride	1.51E-10	4.48E-11	2.44E-11	1.76E-11	1.44E-11	9.26E-12
	Dust (PM2.5–PM10)	0.012299	0.007615	0.003107	0.002168	0.001717	0.001031
Emissions to Water							
	Ammonia	0.000254	8.38E-05	0.000552	0.000419	0.000353	0.000231
	Nitrate	0.009385	0.003587	0.009073	0.005458	0.004344	0.002731
	Phosphorus	0.000421	0.000272	0.00091	0.000527	0.000417	0.00026

Table 3-10. LCI results (kg of each material) for the wiper systems

Type	Flow	Disposable (Worst)	Disposable (Best)	Reusable (Worst)	Reusable (Mid–High)	Reusable (Mid–Low)	Reusable (Best)
Resources							
	Crude oil	0.505965	0.364091	0.096692	0.058579	0.041688	0.027592
	Hard coal	0.442995	0.394657	0.368757	0.261062	0.259283	0.197026
	Lignite	0.245682	0.23964	0.059558	0.040506	0.03988	0.028158
	Natural gas	0.82535	0.819847	0.796313	0.465872	0.457326	0.267812
	Uranium	1.40E-05	1.27E-05	9.12E-06	6.46E-06	6.41E-06	4.88E-06
Emissions to Air							
	Carbon dioxide	7.470858	4.637717	3.207994	2.000259	1.93289	1.257854
	Carbon monoxide	0.011657	0.006836	0.002181	0.00145	0.001288	0.000948
	Nitrogen dioxide	0.001346	0.000298	1.00E-06	5.55E-07	5.29E-07	2.93E-07
	Nitrogen oxides	1.89E-05	1.43E-05	1.24E-05	9.53E-06	9.62E-06	4.98E-06
	Sulphur hexafluoride	2.12E-12	1.86E-12	2.07E-12	1.44E-12	1.43E-12	1.07E-12
	Dust (PM2.5–PM10)	0.000767	0.000589	0.000243	0.000172	0.000165	0.000128
Emissions to Water							
	Ammonia	6.48E-06	8.80E-06	3.49E-06	2.37E-06	2.34E-06	1.71E-06
	Nitrate	0.001646	0.000829	0.000772	0.000517	0.000506	0.000265
	Phosphorus	8.87E-05	1.55E-05	9.08E-05	5.24E-05	4.92E-05	2.99E-05

Table 3-11. LCI results (kg of each material) for the napkin systems

Type	Flow	Disposable (Worst)	Disposable (Mid–High)	Disposable (Mid–Low)	Disposable (Best)	Reusable (Worst)	Reusable (Mid–High)	Reusable (Mid–Low)	Reusable (Best)
Resources									
	Crude oil	0.498985	0.165358	0.017408	0.015198	0.147737	0.12197	0.074116	0.062826
	Hard coal	0.031565	0.012838	0.035356	0.037381	0.5524028	0.437773	0.270805	0.203645
	Lignite	0.036491	0.015617	0.00719	0.007603	0.1362179	0.112027	0.069142	0.056105
	Natural gas	0.290342	0.121954	0.018278	0.01913	1.2865901	0.941588	0.593181	0.412984
	Uranium	0.000224	9.67E-05	1.39E-05	1.47E-05	7.40E-05	5.59E-05	3.41E-05	2.46E-05
Emissions to Air			1.69E-07	5.42E-08	9.00E-07	9.52E-07	1.18E-05	9.00E-06	5.54E-06
	Carbon dioxide	5.947407	2.435907	0.290152	0.298647	4.9998296	3.767585	2.353802	1.695704
	Carbon monoxide	0.061234	0.026043	0.002245	0.00235	0.0025153	0.001888	0.001159	0.000841
	Nitrogen dioxide	2.09E-07	8.95E-08	3.56E-08	3.77E-08	2.39E-06	1.75E-06	1.05E-06	6.99E-07
	Nitrogen oxides	0.000121	5.21E-05	1.98E-06	2.10E-06	3.20E-05	2.40E-05	1.52E-05	1.33E-05
	Sulphur hexafluoride	7.33E-13	3.12E-13	2.33E-13	2.46E-13	2.98E-12	2.29E-12	1.40E-12	1.01E-12
	Dust (PM2.5–PM10)	0.001916	0.000825	0.000235	0.000249	0.0003217	0.000237	0.00015	0.000101
Emissions to Water			1.35E-06	5.71E-07	3.12E-07	3.30E-07	3.91E-05	3.78E-05	2.37E-05
	Ammonia	0.011935	0.005142	0.000216	0.000227	1.65E-03	0.001148	0.000697	0.000493
	Nitrate	3.63E-05	1.57E-05	5.65E-06	5.99E-06	1.56E-04	0.000101	5.81E-05	2.85E-05
	Phosphorus	0.498985	0.165358	0.017408	0.015198	0.147737	0.12197	0.074116	0.062826

4 Life-Cycle Impact Assessment (LCIA)

As mentioned, the reported impact categories represent impact *potentials*; i.e., they are approximations of environmental impacts that could occur if the emitted molecules would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the reported emissions represent only that fraction of the total environmental load that corresponds to the functional unit.

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1 Normalized Impact Assessment results

The study applies normalization to statistical annual U.S. emissions as a means to establish the order of magnitude with which each product system would contribute to the average per-capita environmental burden of a given year. In Figure 4-1, the results are shown for an exemplar scenario (worst-case disposable isolation gown), to provide some context on the relative magnitude of the different impact categories considered. Because each impact is divided by the respective U.S. per-capita burden, the normalized results are dimensionless. Normalization factors are referenced in Section 0.

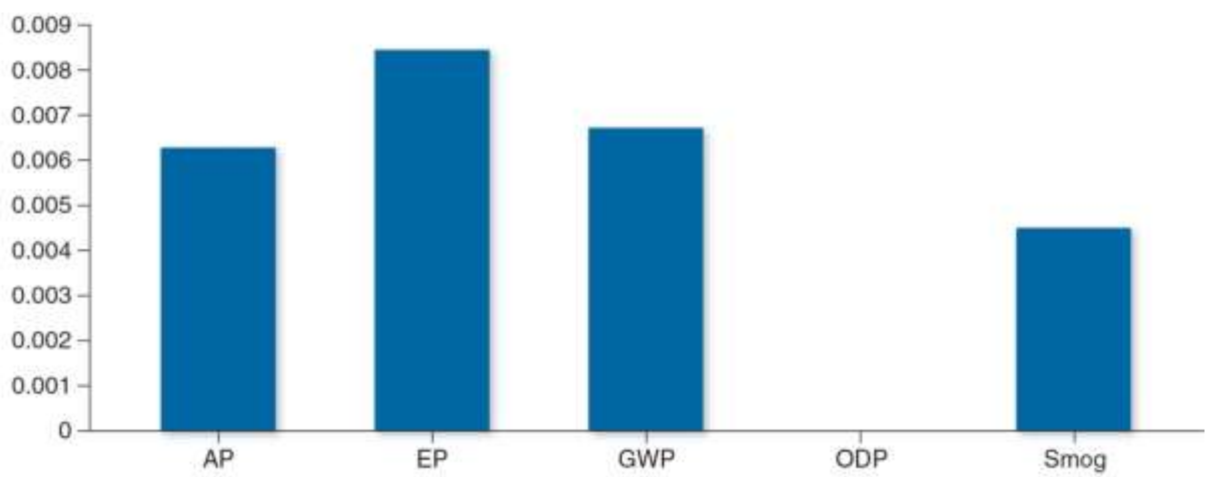

Figure 4-1. Normalized impacts for disposable isolation gown (worst case)

AP, EP, GWP, and smog creation potential are in the same order of magnitude (10^{-3}); therefore, they all represent a comparable fraction of the statistical annual U.S. emissions. Note that the normalized impacts for ODP are so small they can’t be seen on this graph (they are in the range of 10^{-8}). Therefore, the ODP impacts are marginal when considered in the context of the total U.S. emissions profile.

4.2 Detailed Impact Assessment Results

The impact assessment results are calculated using characterization factors published by EPA's Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI), version 2.1 (Bare 2011; EPA 2012).

Abbreviations for the impacts are described in

Table 2-3 above, and are reproduced here for reference.

- Environmental impact categories:
  - Acidification potential (AP) [H^+ moles eq];
  - Eutrophication potential (EP) [kg N eq];
  - Global warming potential (GWP) [kg CO_2 eq];
  - Ozone depletion potential (ODP) [kg CFC 11 eq];
  - Smog creation potential (Smog) [kg O_3 eq];
- Environmental indicators:
  - Primary energy demand (PED) [MJ lower heating value]

In the following graphs, the ranges of possible values for each scenario are represented by floating bars. Because higher environmental burden is associated with the "worst case, the worst-case scenario is represented by the upper limit of the stacked bar, and the best-case scenario is represented by the lower limit. Any intermediate scenarios are then represented by the borderline between different bar segments. An example results graph is shown in Figure 4-2.

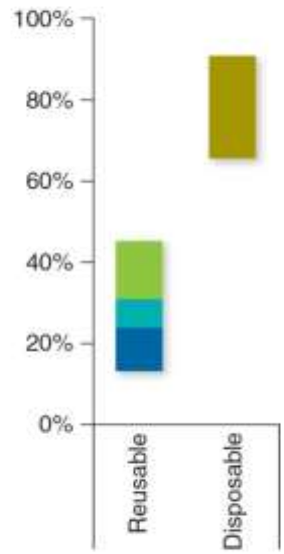

Figure 4-2. Example results graph

4.2.1 Isolation Gown

Results are shown in Figure 4-3 for the isolation gown scenarios. The functional unit for comparison is 100 use cases.

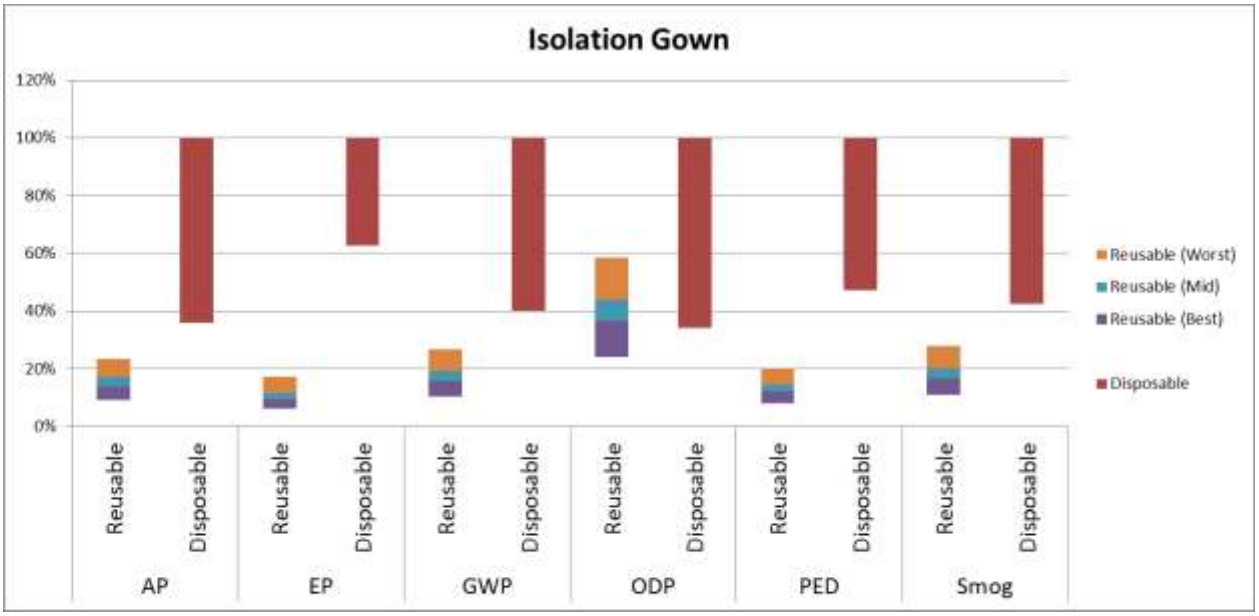

Figure 4-3. Isolation gown LCA results per 100 use cases

Reusables appear to have a lower environmental impact than disposables in every impact considered, with the sole exception of ozone depletion, where the best-case disposable scenario falls between mid-high and mid-low reusables. The reusable ozone depletion comes mainly from upstream energy use in textile manufacturing.

Global warming impacts are shown in Figure 4-4, with burdens split across the different life cycle stages. Breakdowns for additional impact categories are presented in the Annex.

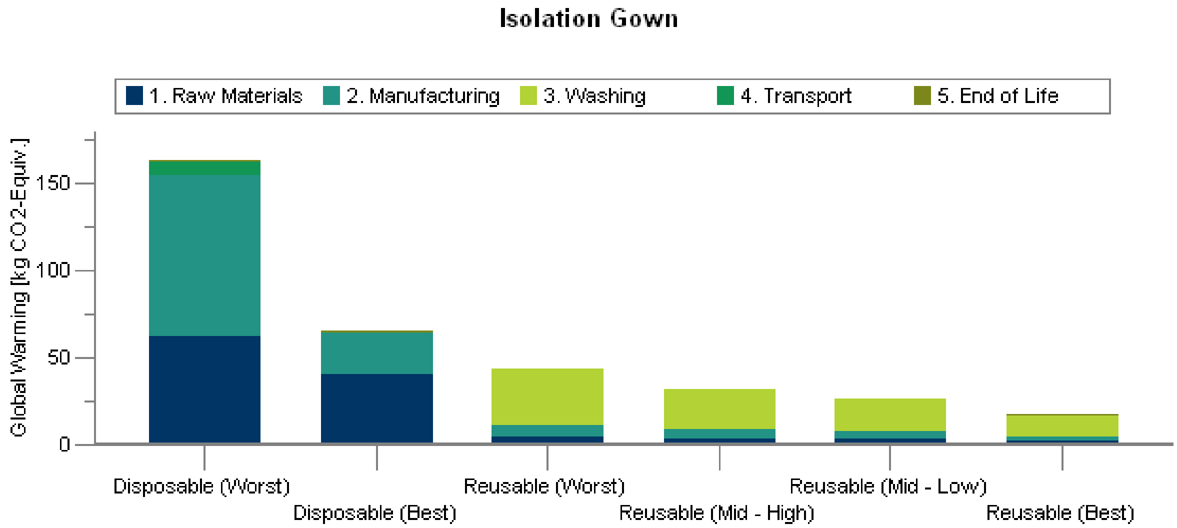

Figure 4-4. Isolation gown GWP breakdown

The disposables' impacts are dominated by the raw materials (polypropylene) and manufacturing of single-use gowns. The reusable products' main impacts are use-phase washing and manufacturing.

For disposables, the key difference between best- and worst-case global warming is the manufacturing. For reusables, use-phase variation outweighs all other life-cycle phase differences.

4.2.2 Wiper

Results are shown in Figure 4-5 for the wiper scenarios. The functional unit for comparison is 100 use cases.

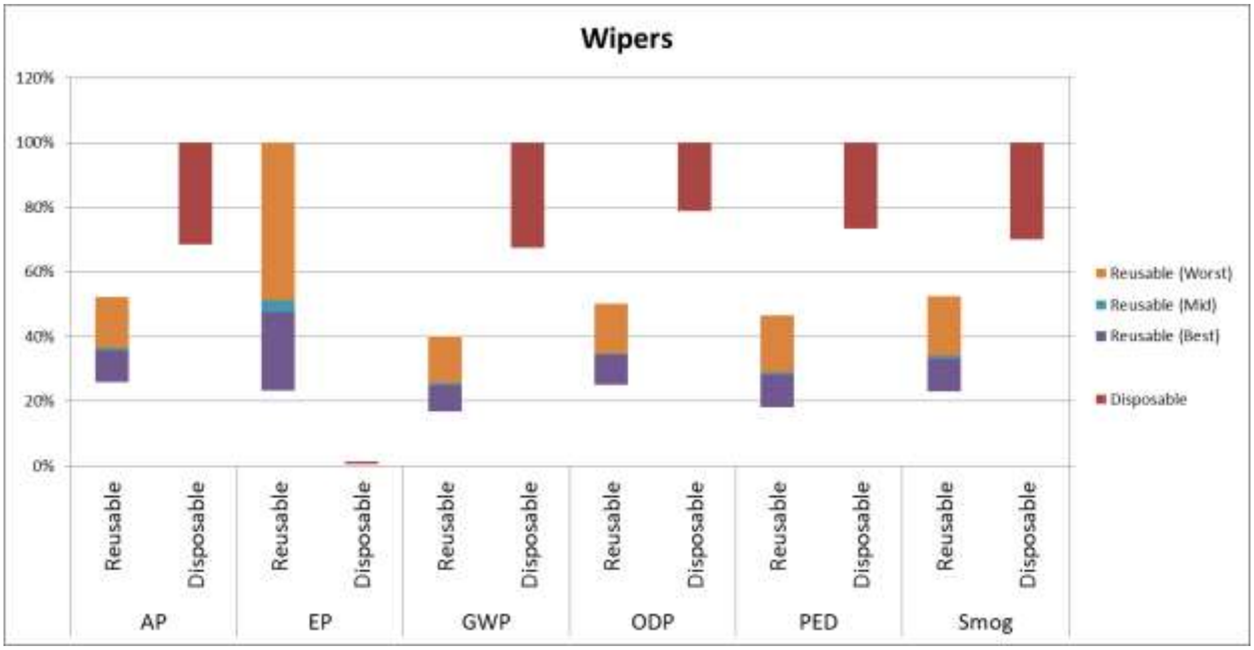

Figure 4-5. Wiper LCA results for 100 use cases

Reusables appear to have a lower environmental impact than disposables in every impact considered, with the sole exception of eutrophication. The reusables eutrophication impacts come from the assumption that washing towels releases 750 mg/L of biological oxygen demand (BOD) to fresh water. This is a single data point provided by a TRSA member company and may not be representative of many other laundry facilities.

Global warming impacts are shown in Figure 4-6, with burdens split across the different life-cycle stages. Breakdowns for additional impact categories are available on request.

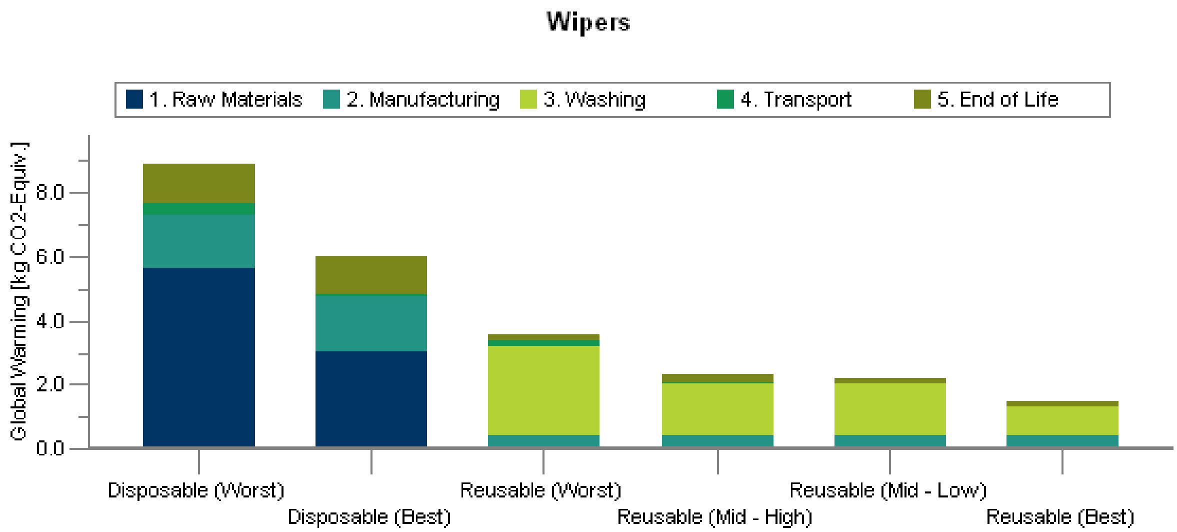

Figure 4-6. Wiper GWP breakdown

The disposables' impacts are dominated by the raw materials (polyester) and manufacturing of single-use wipers. The reusable products' main impacts come from use-phase washing.

For disposables, the key difference between best- and worst-case scenarios lies in the raw materials. For reusables, differences across the scenarios are driven by use-phase energy variability.

4.2.3 Napkin

Results are shown in Figure 4-7 for the napkin scenarios. The functional unit for comparison is 100 napkin uses, as opposed to meals. While multiple disposable napkins are sometimes used during a meal, when a single cloth napkin would have otherwise sufficed, no quantitative data regarding the prevalence of this behavior could be located, so we did not evaluate impacts based on 100 meals (which could require more than 100 disposable napkins). Lacking these data, we have evaluated the two products for 100 uses, ignoring any possible behavior that would otherwise affect the outcome.

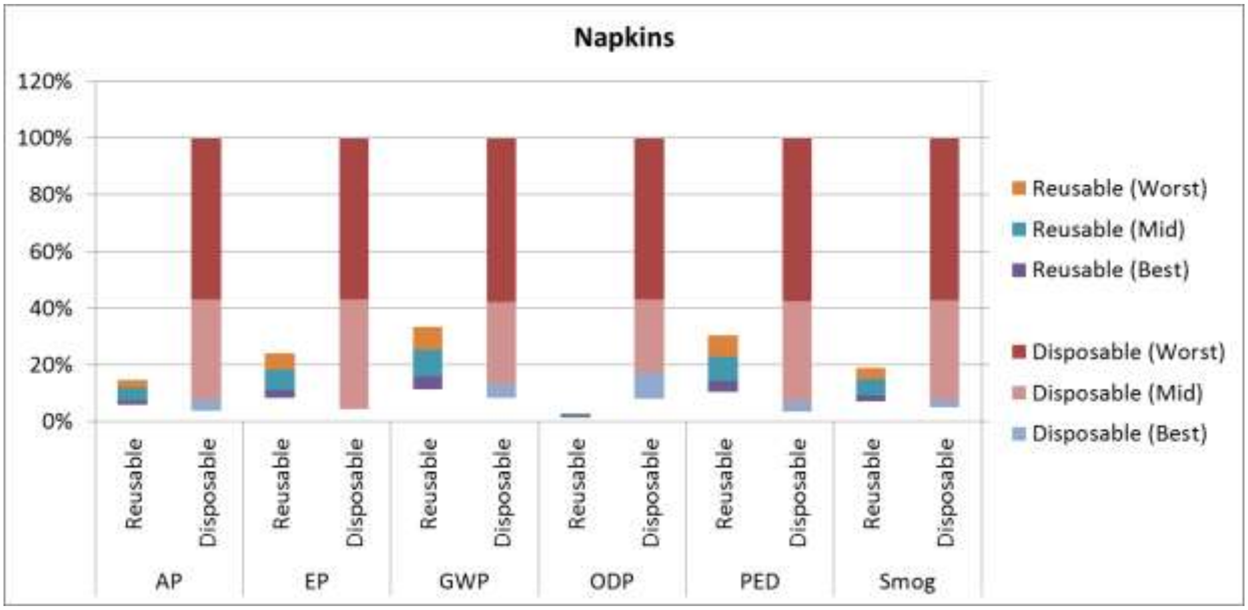

Figure 4-7. Napkin LCA results for 100 use cases

For napkins, the best- and worst-case scenarios overlap each other based on the different assumptions about pulp-making, weight and recycled content, and use-phase washing. Considering the worst-case scenarios, disposables appear to have considerably higher impacts than all reusable impacts. However, for those impacts, best-case and mid-low disposables have an impact comparable to or lower than best-case and mid-low reusables. With no further indication of the probabilities of the displayed scenarios, the conclusion has to be that each product has the potential to render significantly higher burden than the other.

As described in Section 3.4.2, we chose to evaluate disposable napkins with the baseline pulp-making process from the Environ report. Although additional scenarios could have been created to widen the range of possible pulp-making impacts, we varied the paper-making impacts only between high-impact and low-impact paper-making. Examining the life-cycle impacts in more detail, we found that the pulp- and paper-making steps have a fairly similar share of the burden. Table 4-1 shows the impacts of pulp- and paper-making for each of the disposable napkin scenarios.

Table 4-1. Impact of pulp and paper making in isolation

Disposable	Process	AP (H+ mol eq.)	EP (kg N eq.)	GWP (kg CO2 eq.)	ODP (kg R-11 eq.)	Smog (kg O3 eq.)
Worst Case	Paper making	3.246419	0.005825	5.519423	3.9E-09	0.66958
	Pulp making	1.800657	0.007707	6.890515	8.57E-08	0.312114
Mid - High	Paper making	1.401981	0.002515	2.383588	1.69E-09	0.289161
	Pulp making	0.777622	0.003328	2.9757	3.7E-08	0.134788
Mid - Low	Paper making	0.074116	0.000102	0.292971	1.39E-10	0.016631
	Pulp making	0.318047	0.001326	1.184022	1.55E-08	0.057335
Best Case	Paper making	0.078469	0.000108	0.310175	1.47E-10	0.017608
	Pulp making	0.120259	0.000389	0.343596	7.16E-09	0.028633

Comparing the impacts of pulp and paper making for each impact category, the pulp- and paper-making impacts are fairly close to each other (typically not more than double or smaller than half of each other), with exceptions occurring for the mid-low disposable product. This product is an exception, because it has 70% virgin pulp (fairly high impact) paired with low-impact paper making, whereas the other scenarios have either 100% virgin pulp (high impact) paired with high-impact paper making, or 100% recycled pulp (low impact) paired with low-impact paper making.

If the impacts of pulp making were consistently higher than that of paper making, evaluating a wider range of pulp data sets would improve the quality of the study. However, the impacts of pulp and paper making were fairly close to each other, so the choice of using a single pulp data set while varying paper making between high- and low-impact data sets is acceptable.

Global warming impacts are shown in Figure 4-8, with burdens split across the different life-cycle stages. Breakdowns for additional impact categories are available on request.

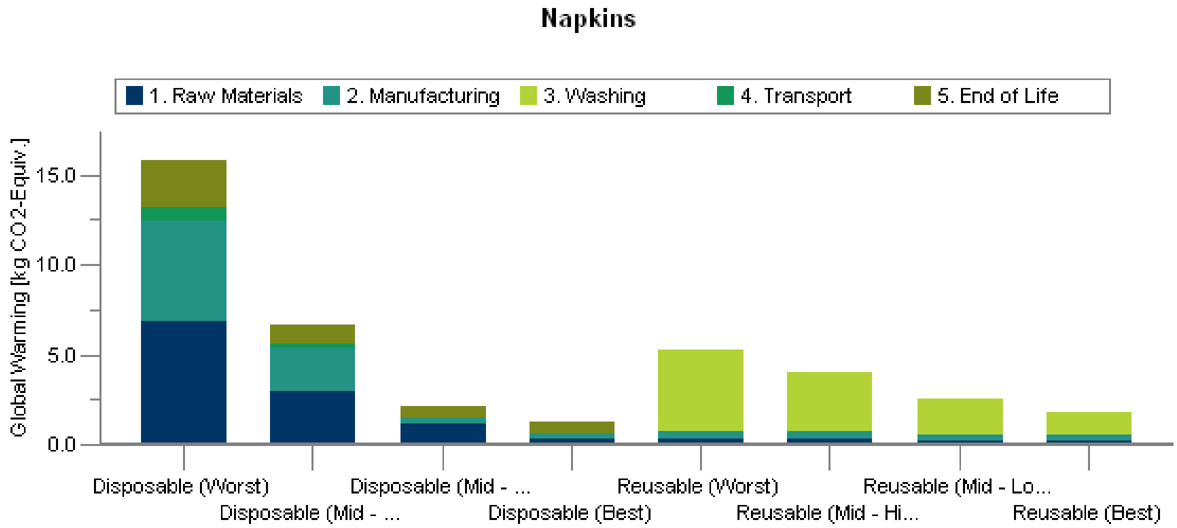

Figure 4-8. Napkin GWP breakdown

Disposables' impacts are dominated by raw materials (paper), followed by paper manufacturing. Reusables are dominated by use-phase washing.

For disposables, variation in raw materials burden is the key difference between the scenarios. For reusables, variation in use-phase washing is the key difference between the scenarios.

5 Interpretation

5.1 Identification of Relevant Findings

In summary, disposables' impacts are driven by raw materials, followed by manufacturing energy. Reusables' impacts are dominated by use-phase washing and, to a limited extent, by raw materials production.

Reusable isolation gowns appear to have a lower environmental impact than the disposable products analyzed in every impact considered, with the sole exception of ODP. Reusable wipers appear to have a lower environmental impact than the disposable products analyzed in every impact considered, with the sole exception of EP. For napkins, the results are mixed - the best- and worst-case scenarios overlap each other based on the different assumptions we make about pulp-making, weight, recycled content, and use-phase washing.

5.2 Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated, or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the method applied on a study serving as a data source), and representativeness (geographic, temporal, and technological).

To meet these requirements and ensure reliable results, first-hand industry data were used in combination with literature and background LCA information from the GaBi 2012 database. The LCI data sets from the GaBi 2012 database are widely distributed and used with the GaBi 6 Software. The data sets have been used in LCA models worldwide in industrial and scientific applications, in both internal evaluations and many critically reviewed and published studies. In the process of providing these data sets, they are cross-checked with other databases and values from industry and science.

5.2.1 Precision and Completeness

- **Precision:** Foreground data were based on primary data whenever possible. Literature data were cross-checked against primary data or existing data from confidential sources to ensure the highest precision available, because primary data on manufacturing and product composition were often unavailable. All background data were GaBi data with the documented precision**.**
- **Completeness:** Each unit process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. In cases where primary data collectors could not provide inventory of similar completeness, we used average or representative data from other providers to supplement the gaps.

5.2.2 Consistency and Reproducibility

- **Consistency:** To ensure consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases. Allocation and other methodological choices were made consistently throughout the model.
- **Reproducibility:** Reproducibility is warranted as much as possible through the disclosure of input-output data, data-set choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

5.2.3 Representativeness

- **Temporal:** All primary data were collected for the year 2012. Some literature data were considerably older, but cross-checks against confidential data from other clients showed that the ranges published are still applicable. All background data come from the GaBi 6 2012 databases and are representative of the years 2006–2010.
- **Geographic:** All primary and secondary data were collected specific to North America when possible. The only notable exception is that kraft pulp and papermaking inventory data were based on European best available technology and then were modeled with North American LCIs. Geographic representativeness is considered to be high.
- **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used (see Chapter 2.9). Technological representativeness is considered to be good.

5.3 Completeness, Sensitivity, and Consistency

5.3.1 Completeness

All relevant process steps for each product system were considered and modeled to represent each specific situation. The process chain is considered sufficiently complete with regard to the goal and scope of this study.

5.3.2 Sensitivity Analysis on Single Parameters

The scenarios (worst, mid-high, mid-low, and best) are a combination of different parameter values; therefore, the following sections show the effect on global warming of modifying each parameter in isolation. Each graph below shows GWP of the scenarios as bars on the primary y-axis, and sensitivity factor as points on the secondary y-axis.

The sensitivity factor is calculated by dividing the percent change in GWP from the baseline by percent change in the parameter being evaluated. In the isolation gown example, switching from a 250-mile delivery distance to a 100-mile distance (a parameter change of –60%) yields a drop in GWP from 162.87 to 158.51 (an impact change of –3%). The sensitivity factor is –3% / –60% = 4%. In the case of parameters for which increasing value decreases impact (such as increasing truck utilization or increasing number of lifetime uses), this inverse relationship is designated with a negative sensitivity factor. The sensitivity factor for each scenario is shown as a dot on the graph's right-hand y-axis.

For scenarios where a combination of individual parameters are changed (i.e., worst vs. best washing) or a binary parameter is changed (i.e., high-impact pulp vs. low-impact pulp), no sensitivity calculation is possible.

5.3.2.1 Isolation Gown

The parameters evaluated for disposables include delivery distance, delivery utilization, product weight, and manufacturing energy. The parameters evaluated for reusables include delivery distance, delivery utilization, product weight, manufacturing energy, number of uses, and washing scenario.

The effects of switching individual parameters are shown for disposables in Figure 5-1 and for reusables in Figure 5-2. The worst-case gown scenarios are shown as the baselines, as defined in Table 3-3. The other bars show the net GWP when changing a single parameter to its best-case value while keeping all other parameters at their worst-case values.

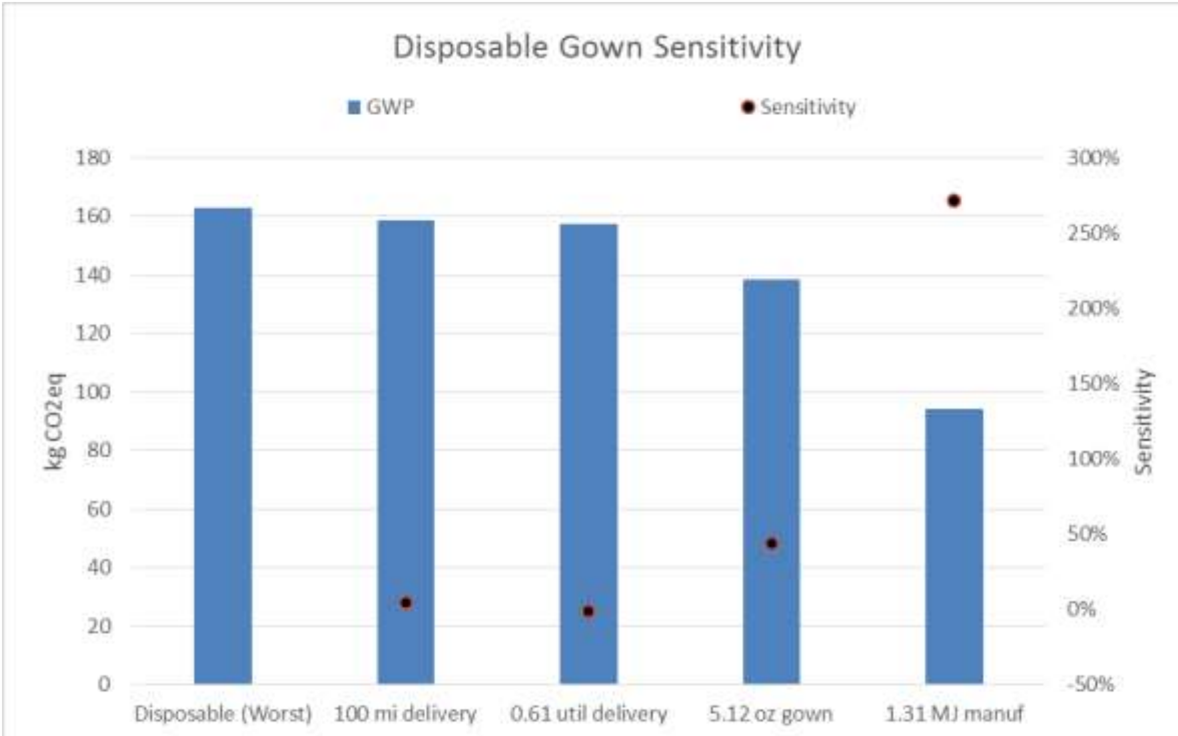

Figure 5-1. Disposable gown parameter sensitivity (GWP)

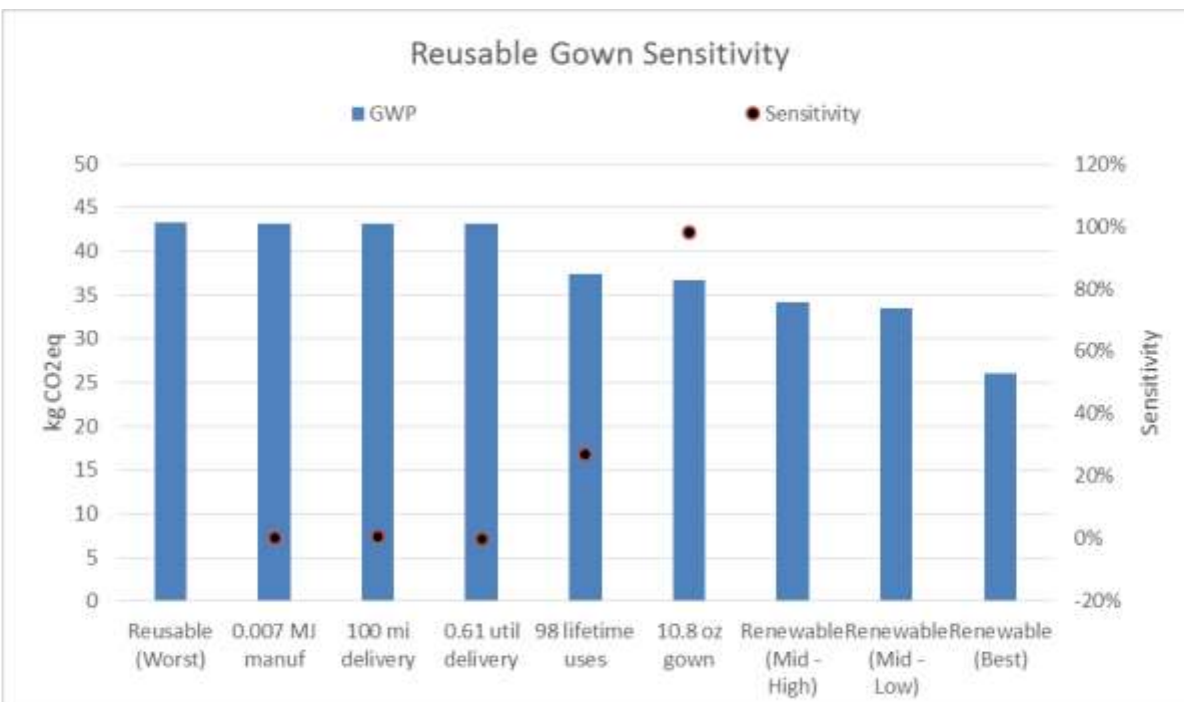

Figure 5-2. Reusable gown parameter sensitivity (GWP)

Sensitivity analysis for disposables shows that reducing manufacturing energy from 5.16 to 1.31 MJ has the largest single effect on an absolute level, which is confirmed by its high sensitivity factor. Improved washing has the largest effect for reusable wipers, followed by reducing product weight from 12.8 to 10.8 oz and increasing the number of uses from 49 to 98. For both disposables and reusables, changing the truck distance and utilization (amount of laundry as a fraction of truck capacity) doesn't affect the overall results in a meaningful way.

5.3.2.2 Wiper

The parameters evaluated for the disposables include delivery distance, delivery utilization, pulp recycled content, and high- or low-impact pulp. The parameters evaluated for the reusables include delivery distance, delivery utilization, product weight, and washing scenario.

The effects of switching individual parameters are shown for disposable scenarios in Figure 5-3, and for reusables in Figure 5-4. Worst-case scenarios are shown as the baselines, as defined above in Table 3-5. The other bars show the net GWP when changing a single parameter to its best-case value while keeping all other parameters at their worst-case values.

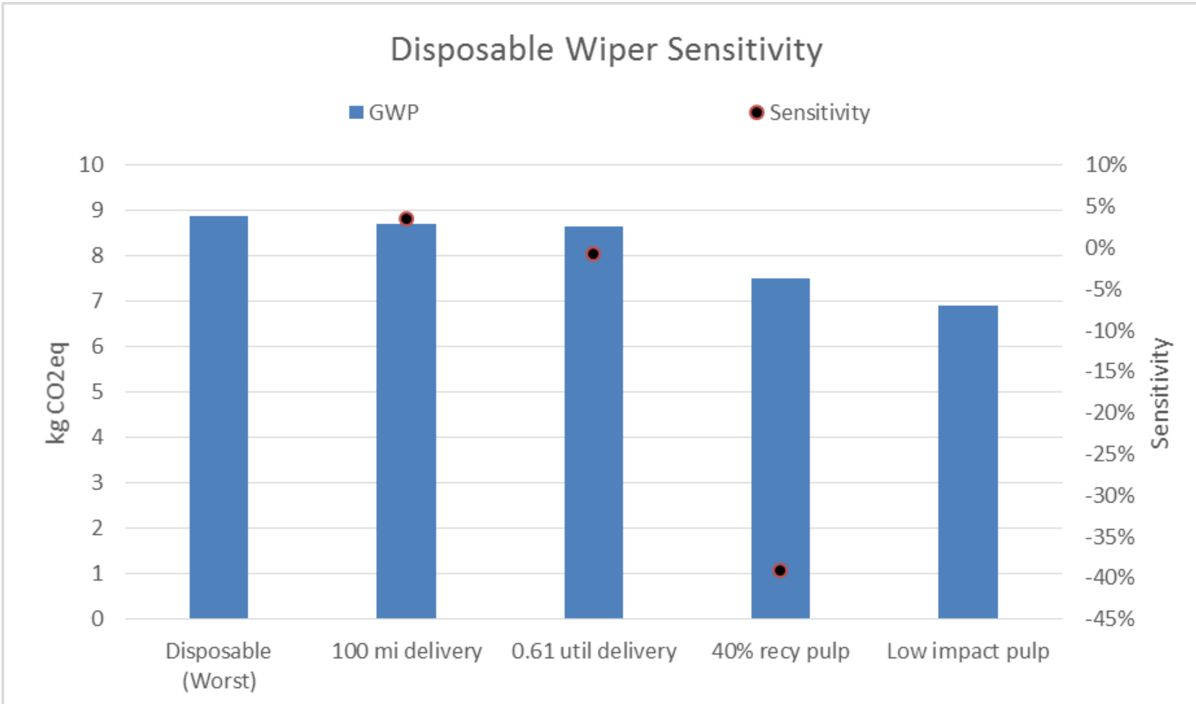

Figure 5-3. Disposable wiper parameter sensitivity (GWP)

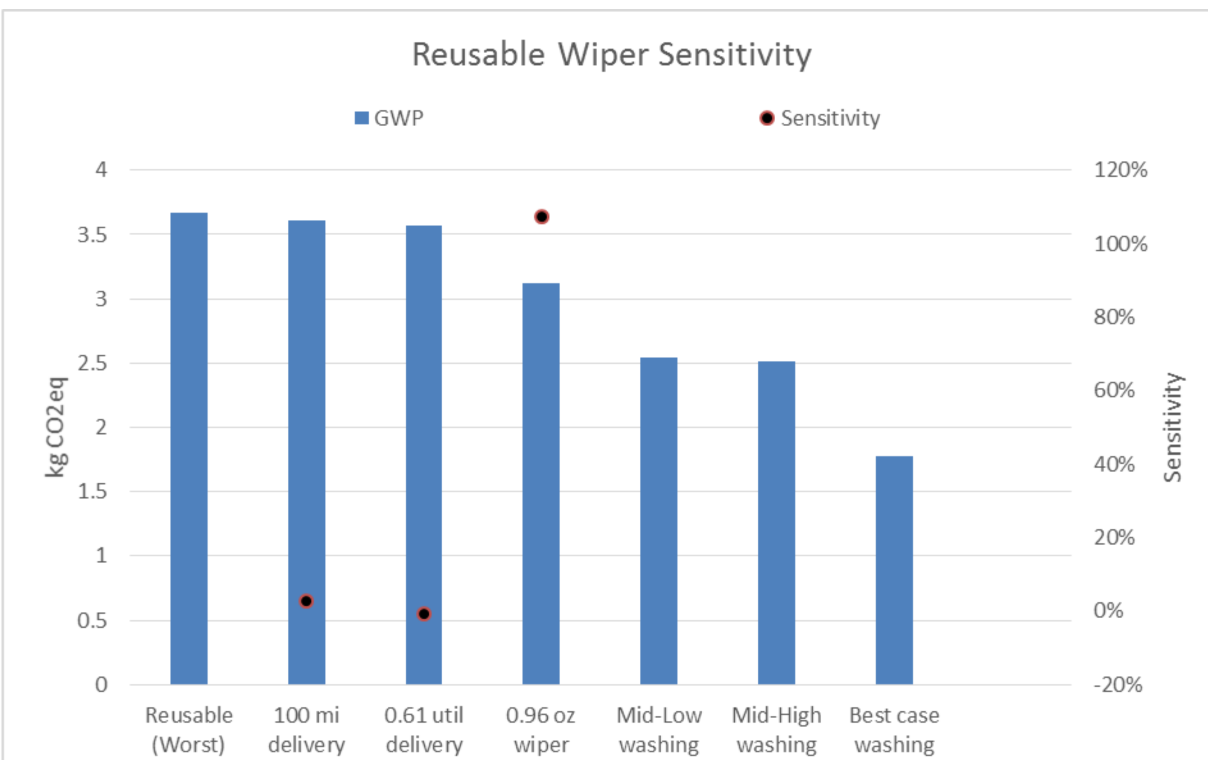

Figure 5-4. Reusable wiper parameter sensitivity (GWP)

Sensitivity analysis for disposables shows that switching from high-impact to low-impact paper has the largest single effect on an absolute level, followed by increasing the recycled content of the pulp. Other changes are minor. The largest reductions for reusables come from improved washing. For both disposables and reusables, changing the truck distance and utilization (amount of laundry as a fraction of truck capacity) doesn't affect the overall results in a meaningful way.

5.3.2.3 Napkin

The parameters evaluated for disposables include delivery distance, delivery utilization, product weight, recycled content of the paper, and high- or low-impact paper making. The parameters evaluated for reusables include delivery distance, delivery utilization, product weight, number of uses, manufacturing energy, and washing scenario.

The effects of switching individual parameters are shown for disposable scenarios in Figure 5-5, and for reusables in Figure 5-6. Worst-case napkins are shown as the baseline, as defined above in Table 3-7. The other bars show the net GWP when changing a single parameter to its best-case value while keeping all other parameters at their worst-case values.

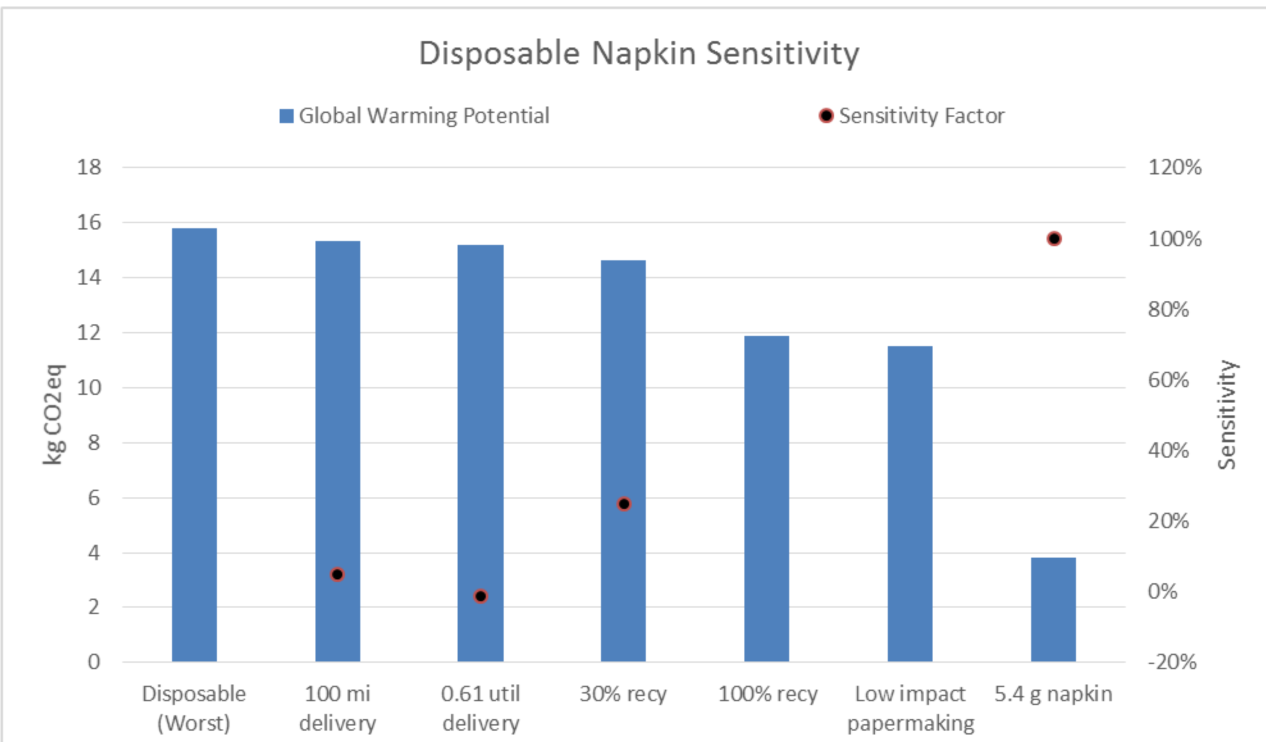

Figure 5-5. Disposable napkin parameter sensitivity (GWP)

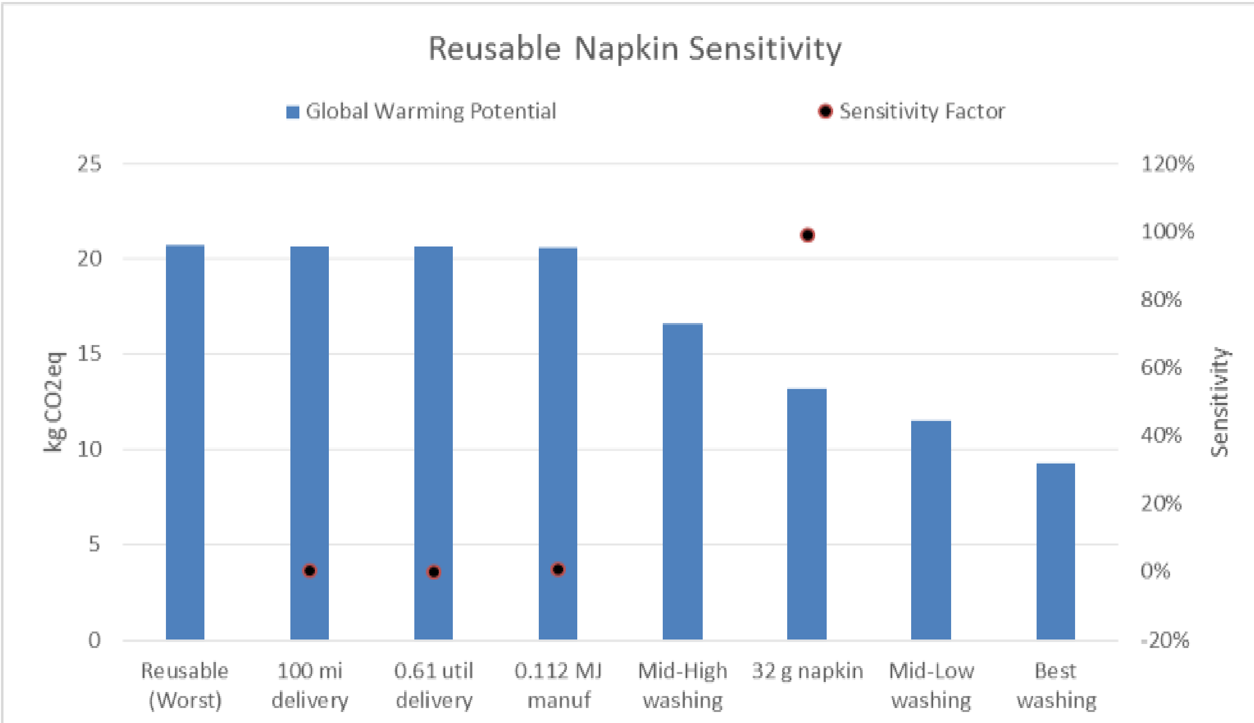

Figure 5-6. Reusable napkin parameter sensitivity (GWP)

Sensitivity analysis for disposables shows that reducing product weight and switching from high-impact to low-impact paper have the largest effects. Increasing recycled content shows a considerable improvement as well. Improved washing has the largest effect for reusable napkins, followed by reducing product weight from 50.8 grams to 32.1 grams. For both disposables and reusables, changing the truck distance and utilization (amount of laundry as a fraction of truck capacity) doesn't affect the overall results in a meaningful way.

5.3.3 Consistency

All assumptions, methods, and data were found to be consistent with the study's goal and scope. Differences in background data quality were minimized by using LCI data from the GaBi 6 2012 databases. System boundaries, allocation rules, and impact assessment methods were applied consistently throughout the study.

5.4 Conclusions, Limitations, and Recommendations

5.4.1 Conclusions

In summary, reusable isolation gowns appear to have clear environmental benefit compared to the disposable products analyzed, except for ODP. The benefit comes from differences in raw-material weight and manufacturing energy. For wipers, reusables appear to have a clear environmental benefit compared to the disposable products analyzed, except for EP, which is linked to wastewater emissions during washing that may not be relevant to all facilities. For napkins, reusables and disposables are similar if comparing best case products though disposables have higher impact if comparing worst case products. Product weight has the greatest influence on results, followed by the choice of high- or low-burden paper making, recycled content, and use-phase washing variability.

5.4.2 Limitations and Assumptions

Only limited information on material manufacturing was taken from primary sources, so literature and secondary data were cross-checked against confidential client manufacturing details to validate the assumptions when possible. Reduced reliance on literature would have increased the data quality, but was not possible within the scope, timeline, and budget.

We assume that a premium disposable napkin meets the same function as a reusable napkin, though personal experience suggests that more than one disposable napkin may be used during a meal, especially at the lighter end of the napkin spectrum. If additional disposable napkins were used in a meal where only a single reusable were used, the disposable scenarios would all have higher impact than the reusable scenarios.

5.4.3 Recommendations

In the cases of isolation gowns and wipers, reusables appear to provide a significant environmental benefit compared to disposables. In the case of napkins, lighter weight disposable products and reusables washed most efficiently exhibit the lowest per-wiping environmental impacts. The importance of sourcing low-energy or recycled materials is especially pronounced for products made from paper. Transportation is a small contributor, so only limited effort should be spent on improving route efficiency or truck utilization.

6 References

(Bare, 2011)	Bare, J. TRACI 2.0: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts 2.0. Clean Technology Environmental Policy. 2010
(Cotton, Inc., 2012)	Cotton Inc. Life Cycle Assessment of Cotton Fiber and Fabric. 2012. Full Report available at http://cottontoday.cottoninc.com/sustainability-about/LCI-LCA-Cotton-Fiber-Fabric/
(Earth First, 2013)	Earth First Product Catalog. http://www.earthfirstpaper.com/consumer.html . Last accessed in June 2014
(Environ, 2012)	Environ International Corporation. Life Cycle Assessment of Deinked and Virgin Pulp; Prepared for National Geographic. 2012
(EPA, 2012)	Environmental Protection Agency (EPA). Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) version 2.1 User's Manual. 2012
(GP Essentials, 2013)	Georgia Pacific Product Catalog; http://productcatalog.gp.com/Product.aspx?Pid=7752&Cat=6306&View=1 . Last accessed in June 2014
(GP Preference, 2013)	Georgia Pacific Product Catalog; http://productcatalog.gp.com/Product.aspx?Pid=17016&Cat=6262&View=1 . Last accessed in June 2014
(Guinee, 2001)	Guinée, J. B. (ed.). Handbook on life cycle assessment: Operational guide to the ISO-standards. Centre for Milieukunde Leiden (CML). 2001.
(IVL, 2011)	Swedish Environmental Research Institute (IVL). Life cycle assessment of premium single-use and reusable napkins for restaurant dinners. Prepared for Duni AB. 2011. Retrieved from http://www.duni.com/Global/AboutUs/Environment/Documents/U3473_Report_Duni-LCA-Critically-reviewed.pdf in June 2014
(ISO 14040, 2006)	International Organization for Standardization. ISO 14040:2006. Environmental Management – Life Cycle Assessment – Principles and Framework.
(ISO 14044, 2006)	International Organization for Standardization. ISO 14044:2006. Environmental management -- Life cycle assessment -- Requirements and guidelines.
(Joint Research Centre, 2012)	Joint Research Centre. Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper, and Board. Draft May 2012

(Meredith, 2011)	Meredith, E. Black Ivory Napkin Test University of Kentucky Textile Lab in 2011.
(Malkan, 1994)	Malkan, S. An Overview of Spunbonding and Meltblowing Technologies. Paper presented at 1994 Nonwovens Conference. 1994
(McIlvane, 2009)	McIlvaine Company. A White Paper on Performance, Cost Per Use, and Environmental Impact of Single-Use and Reusable Surgical Gowns & Drapes. 2009. Last retrieved from http://mcilvainecompany.com/SURS/subscriber/Text/White%20Paper%208-17-09.pdf in June 2014
(PE INTERNATIONAL, 2011)	PE INTERNATIONAL. GaBi dataset documentation for the software-system and databases, LBP, University of Stuttgart and PE INTERNATIONAL GmbH, Leinfelden-Echterdingen. 2011 (http://documentation.gabi-software.com/)
(Pullman, 1997)	Pullman, W et al. Environmental Assessment of Shop Towel Usage in the Automotive and Printing Industries. (EPA). 1997

Annex

Table 1. Isolation gown LCA results

	Units	Disposable (Best)	Disposable (Worst)	Reusable (Best)	Reusable (Mid–Low)	Reusable (Mid–High)	Reusable (Worst)
Acidification	kg SO_2 eq.	0.205	0.571	0.0521	0.0794	0.0974	0.133
Eutrophication	kg Nitrogen eq.	0.12	0.191	0.0117	0.0181	0.0222	0.0327
Global Warming	kg CO_2 eq.	65.5	163	16.8	25.8	31.2	43.5
Ozone Depletion	kg CFC-11 eq.	1.89E-08	5.55E-08	1.33E-08	2.03E-08	2.44E-08	3.24E-08
Primary Energy	MJ	1680	3560	280	428	519	722
Smog Creation	kg O_3 eq.	2.66	6.28	0.68	1.04	1.26	1.75

Table 2. Wiper LCA results

	Units	Disposable (Best)	Disposable (Worst)	Reusable (Best)	Reusable (Mid–Low)	Reusable (Mid–High)	Reusable (Worst)
Acidification	kg SO_2 eq.	0.0108	0.0157	0.00409	0.00561	0.00572	0.00823
Eutrophication	kg Nitrogen eq.	0.00146	0.00325	0.0517	0.106	0.113	2.22E-01
Global Warming	kg CO_2 eq.	6.01	8.89	1.49	2.21	2.29	3.57
Ozone Depletion	kg CFC-11 eq.	1.14E-09	1.45E-09	3.66E-10	4.98E-10	5.04E-10	7.3E-10
Primary Energy	MJ	87.1	118	21.6	33.4	34.5	55.1
Smog Creation	kg O_3 eq.	0.15	0.214	4.91E-02	0.071	0.0732	0.112

Table 3. Napkin LCA results

	Units	Disposable (Best)	Disposable (Mid–Low)	Disposable (Mid–High)	Disposable (Worst)	Reusable (Best)	Reusable (Mid–Low)	Reusable (Mid–High)	Reusable (Worst)
Acidification	kg SO_2 eq.	0.199672	0.393618	2.192283	5.097829	0.29866	0.375982	0.603508	0.750186
Eutrophication	kg Nitrogen eq.	6.21E-04	6.21E-04	6.08E-03	1.41E-02	1.18E-03	1.58E-03	2.60E-03	3.39E-03
Global Warming	kg CO_2 eq.	1.30249	2.098093	6.685911	15.79989	1.793988	2.486705	3.980989	5.283447
Ozone Depletion	kg CFC-11 eq.	7.30E-09	1.57E-08	3.87E-08	8.96E-08	1.34E-09	1.49E-09	2.38E-09	2.64E-09
Primary Energy	MJ	10.03332	20.29294	122.9092	289.3114	30.34069	41.50548	66.30406	87.69368
Smog Creation	kg O_3 eq.	0.050612	0.07826	0.434996	1.013536	0.071859	0.093807	0.150755	0.192318

Normalization Factors

The table below shows normalization factors for the TRACI 2.1 method based on U.S. emissions in 2008. These "equivalences" represent the annual per capita U.S. emissions profile. The "factor" is the inverse of the equivalences. To calculate normalized results, the LCIA results are multiplied by these factors (i.e., divided by per-capita U.S. emissions) for a dimensionless normalized value.

Quantity	Equivalences	Unit	Factor
TRACI 2.1, Acidification Air	90.8	kg SO2-Equiv.	0.011013
TRACI 2.1, Acidification Water	90.8	kg SO2-Equiv.	0.011013
TRACI 2.1, Ecotoxicity (recommended)	11100	CTUeco	9.01E-05
TRACI 2.1, Eutrophication Air	21.6	kg N-Equiv.	0.046296
TRACI 2.1, Eutrophication Water	21.6	kg N-Equiv.	0.046296
TRACI 2.1, Global Warming Air	24200	kg CO2-Equiv.	4.13E-05
TRACI 2.1, Human Health Particulate Air	24.2	kg PM2,5-Equiv.	0.041322
TRACI 2.1, Human toxicity, cancer (recommended)	5.07E-05	CTUh	19723.87
TRACI 2.1, Human toxicity, non-canc. (recommended)	0.00105	CTUh	952.381
TRACI 2.1, Ozone Depletion Air	0.161	kg CFC 11-Equiv.	6.21118
TRACI 2.1, Resources, Fossil fuels	17300	MJ surplus energy	5.78E-05
TRACI 2.1, Smog Air	1390	kg O3-Equiv.	0.000719

Review of the Report "Comparative Life Cycle Assessment of Reusable vs. Disposable Textiles" (Dated June 17, 2014), Conducted for the Textile Rental Services Association of America by PE International and Exponent

Review Statement Prepared by the Critical Review Panel:

Arpad Horvath (Chair), James Mellentine, Christopher M. Pastore

July 28, 2014

The review of this report has found that:

- the approach used to carry out the LCA is consistent with the ISO 14040:2006 principles and framework and the ISO 14044:2006 requirements and guidelines,
- the methods used in the LCA appear to be scientifically and technically valid,
- the interpretations of the results reflect the limitations identified in the goal of the study,
- the report is transparent concerning the study steps and consistent for the purposes of the stated goals of the study.

This review statement only applies to the report named in the title, available to the Critical Review Panel on July 9, 2014, but not to any other document versions, derivative reports, excerpts, press releases, and similar.

Arpad Horvath

Consultant, Berkeley, California

James Mellentine

Sustainable Solutions Corporation

Christopher M. Pastore

Philadelphia University