This Life Cycle Assessment was conducted for the American Reusable Textile Association's LCA Committee with contributions from both reusable and disposable isolation gown supplier members.

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Major Article

Environmental considerations in the selection of isolation gowns: A life cycle assessment of reusable and disposable alternatives

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Key Words:
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Background: Isolation gowns serve a critical role in infection control by protecting healthcare workers, visitors, and patients from the transfer of microorganisms and body fluids. The decision of whether to use a reusable or disposable garment system is a selection process based on factors including sustainability, barrier effectiveness, cost, and comfort. Environmental sustainability is increasingly being used in the decision-making process. Life cycle assessment is the most comprehensive and widely used tool used to evaluate environmental performance.

Methods: The environmental impacts of market-representative reusable and disposable isolation gown systems were compared using standard life cycle assessment procedures. The basis of comparison was 1,000 isolation gown uses in a healthcare setting. The scope included the manufacture, use, and end-of-life stages of the gown systems.

Results: At the healthcare facility, compared to the disposable gown system, the reusable gown system showed a 28% reduction in energy consumption, a 30% reduction in greenhouse gas emissions, a 41% reduction in blue water consumption, and a 93% reduction in solid waste generation.

Conclusions: Selecting reusable garment systems may result in significant environmental benefits compared to selecting disposable garment systems. By selecting reusable isolation gowns, healthcare facilities can add these quantitative benefits directly to their sustainability scorecards.

BACKGROUND

Isolation gowns serve a critical role in infection control by protecting healthcare workers, visitors, and patients from the transfer of microorganisms and body fluids in isolation settings. These gowns and other medical textiles are available in reusable and disposable alternatives. The selection of a reusable or disposable textile system for use in hospitals is a decision that depends on factors such as barrier effectiveness, cost, comfort, and sustainability.[1-3]

The barrier effectiveness, cost, and comfort of isolation gowns have been covered previously in the literature. The American National Standards Institute (ANSI) and the Association for the Advancement of Medical Instrumentation (AAMI) have established standards to quantify the liquid-barrier performance of isolation gowns and other medical textiles.[4] A reusable gown and a disposable gown with the same barrier rating are expected to exhibit similar barrier effectiveness. A recent case study showed that reusable isolation gown systems resulted in a 30% reduction in costs compared to disposable gown systems.[5] Similar case studies have shown that reusable operating room linens, surgical packs, and towels provide significant cost savings compared to disposable alternatives.[1,6-8] The evaluation of the comfort of isolation gowns is complex and involves human perception. Although individual features of isolation gowns have been found to affect hospital staff and visitor compliance, whether a gown is reusable or disposable has been found to have little to no impact on compliance.[9]

Sustainability is a significant factor to consider when selecting between reusable and disposable textile systems. Previous environmental studies have focused on surgical gowns and packs, with isolation gown systems being largely ignored.[10-12] As hospitals and healthcare providers move toward more sustainable or "green" practices, publicly available, transparent environmental information is needed to support product decisions.

Comparative life cycle studies by McDowell[10], Carre[13], Van den Berghe and Zimmer[14], and Overcash[12] compared reusable and disposable surgical gown systems. A study by Jewell and Wentsel[15] compared reusable and disposable isolation gown, automotive wiper,

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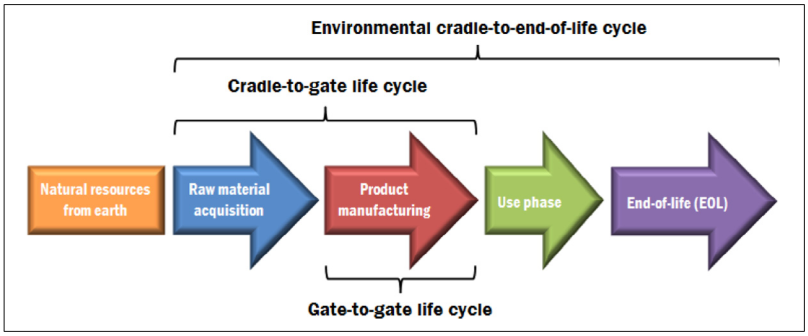

Fig 1. Life cycle scope for product analysis

and restaurant napkin systems. All five of these studies found that reusable textile systems provided substantially better environmental profiles than disposable systems. However, analysis of these available life cycle data is often limited by the transparency and depth of information in these respective reports. Thus, the objectives of this study were (1) to compare 4 environmental impacts (energy, global warming potential, water use, and solid waste consumption) of reusable and disposable isolation gowns; (2) to clearly show what parts of the life cycle are important to the result; and (3) to provide a sensitivity analysis for important parameters.

MATERIAL AND METHODS

The most common analyitcal tool to evaluate the environmental benefits and impacts of products is the life cycle assessment (LCA). An LCA is a structured approach to environmental research that includes 4 phases. The first phase is to determine the goal(s) and scope of the study. The second phase, known as the life cycle inventory (LCI) analysis, includes the compilation of an inventory of material and energy inputs and outputs for a complete product system. In the third phase, known as the life cycle impact assessment, the material and energy inventories compiled in the second phase are used to determine the potential environmental impacts of the system, such as global warming potential. The final phase is the interpretation, which includes a discussion of the results, sensitivity analysis, and conclusions. The process is iterative, so that the interpretation can help lead to refinements in the study.

The backbone of an LCA is the LCI. An LCI is the estimation of energy use and material use (and loss) of each manufacturing plant or node, such as a fabric manufacturing plant or oil refinery. Each plant or node is referred to as a gate-to-gate (GTG) LCI. The GTGs are added together to give a cradle-to-gate (CTG) LCI, from the cradle (natural materials in the earth) to the gate (a final product, such as a reusable isolation gown). Energy use is given as electricity, the use of steam (from boilers) or high-temperature furnaces (for metals), whereas material use is given by the mass balance on each process or service.

After all of the necessary LCIs are compiled, the data are weighted and summed to determine the total impact in environmental categories. For example, several chemical emissions result in global warming effects. Each of these emissions is multiplied by the relevant factor to calculate the total global warming effect as carbon dioxide (CO_2) equivalents. The environmental impacts comprise the life cycle impact assessment.

The LCI data used in the isolation gown LCA were from the Environmental Clarity, Inc. LCI Database.[16] LCI data were transparent, with a strong emphasis on process or design-based methodology. Detailed reports for all GTG LCIs used in this LCA are available from Environmental Clarity, Inc. Each LCI report included a summary of the process mass and energy flows as well as a review of literature pertinent to the process. The LCIs used for this study included data on the production of intermediate materials in the supply chains, the manufacture of gowns, the laundry process, wastewater treatment, end-of-life landfill disposal, and transportation.

Reusable and disposable isolation gown systems were compared following LCA guidelines established by the International Organization for Standardization.[17,18] The scope of the study included the complete cradle-to-end-of-life analysis of representative isolation gown systems. The system boundaries included all activities from natural resource extraction from the earth, to gown manufacture, to gown use and/or reuse in healthcare settings, to end-of-life disposition (Figure 1).

The isolation gown was defined as a single-piece, long sleeve, extra-large or one-size-fits-most garment with ANSI/AAMI PB70 Level 1 barrier protection rating. The study did not include other medical textiles used in healthcare settings such as gloves, wipes, or masks. It was recognized that a wide variety of isolation gowns are used in healthcare facilities, with ANSI/AAMI PB70 barrier protection ratings ranging from no rating to Level 2. To determine the specifications of representative reusable and disposable isolation gowns for the study, 24 gowns from 8 suppliers were analyzed to determine the typical material compositions and weights. This information was obtained from manufacturer specifications and product data sheets. The suppliers included High Five (Company 1), Kimberley-Clark (Company 2), Medline (Company 3), Precept (Company 4), S2S Global (Company 5), American Dawn (Company 6), Encompass (Company 7), and Fashion Seal (Company 8). Eight of the gowns were individually sampled and found to be within 20% of the manufacturer-specified weight, with 7 of the gowns within 10%. The weights of specific gowns were excluded from reporting to protect the intellectual property of the gown manufacturers. Instead, the average, minimum, maximum, and standard deviation of the weights are given. Sixteen disposable isolation gowns from 5 suppliers were examined (Table 1). All 16 disposable gowns were found to be composed primarily of nonwoven polypropylene fabric. The average weight of the disposable gowns was 63 g, with a minimum of 41 g, maximum of 91 g, and standard deviation of 12 g. Eight reusable isolation gowns from 4 suppliers were examined (Table 2). All 8 reusable gowns were found to be composed of primarily woven polyester fabric. The average weight of the reusable gowns was 240 g, with a minimum of 220 g, maximum of 255 g, and standard deviation of 13 g. Thus, in this study, a 63-g nonwoven polypropylene gown was chosen as representative of disposable isolation gowns. A 240-g woven polyester gown was chosen as representative of reusable gowns.

The basis of comparison, or functional unit, was 1,000 isolation gown uses in a healthcare setting. For disposable or single-use gowns, this included the manufacture, delivery, and disposal of 1,000 gowns.

Table 1
List of disposable isolation gowns examined to determine market representative materials and weights

Manufacturer/Supplier	Product	Primary fabric material	ANSI/AAMI PB70 Rating
Company 1	Gown 1	SMS PP	NR
Company 2	Gown 2	SMS PP	NR
Company 3	Gown 3	SMS PP	NR
Company 3	Gown 4	SMS PP	NR
Company 3	Gown 5	SMS PP	NR
Company 3	Gown 6	SMS PP	NR
Company 3	Gown 7	SMS PP	Level 2
Company 3	Gown 8	SMS PP	Level 2
Company 4	Gown 9	SMS PP	Level 1
Company 4	Gown 10	SMS PP	Level 1
Company 5	Gown 11	SMS PP	Level 1
Company 5	Gown 12	SMS PP	Level 1
Company 5	Gown 13	SMS PP	Level 1
Company 5	Gown 14	SMS PP	Level 1
Company 5	Gown 15	SMS PP	Level 1
Company 5	Gown 16	SMS PP	Level 2
Average weight, g		63	
Standard deviation, g		12	
Minimum weight, g		41	
Maximum weight, g		91	

NR, no rating or unknown; *PP*, polypropylene; *SMS*, spunbond-meltblown-spunbond.

Table 2
List of reusable isolation gowns examined to determine market representative materials and weights

Manufacturer/Supplier	Product	Primary fabric material	Mfr. rated uses	ANSI/AAMI PB70 rating
Company 3	Gown 17	Woven PET	75	Level 1
Company 3	Gown 18	Woven PET	75	Level 1
Company 6	Gown 19	Woven PET	–	NR
Company 7	Gown 20	Woven PET	100	NR
Company 7	Gown 21	Woven PET	100	NR
Company 7	Gown 22	Woven PET	100	NR
Company 7	Gown 23	Woven PET	100	NR
Company 8	Gown 24	Woven PET	–	NR
Average weight, g		240		
Standard deviation, g		13		
Minimum weight, g		220		
Maximum weight, g		255		

NR, no rating or unknown; *PET*, polyethelene terephthalate (polyester).

Reusable or multi-use gowns are typically rated by the manufacturer for 75-100 uses before downgrade (Table 2). In this study, a conservative estimate of 60 uses before disposal was used based on gown tracking data from industrial laundry facilities. The lower value is due in part to lost and damaged gowns. Thus, 1,000 reusable gown uses included the manufacture and disposal of 16.7 gowns and the laundry and delivery of 1,000 gowns.

Four environmental impacts and indicators were selected for evaluation in the study:

- Natural resource energy (NRE) consumption, megajoules (MJ) (1 MJ = 0.277 kWh)

NRE, sometimes referred to as primary energy demand, is the total energy of all fuels used in a process. This measure of energy includes losses due to extraction, combustion, and delivery of fuels to produce energy. For additional transparency, energy use was further classified as the consumption of electricity, steam, diesel fuel, or high-temperature heating fluid.

- Global warming potential, kg CO_2 equivalent

Global warming potential, is measured as the CO_2 equivalent of all greenhouse gasses released during the cradle-to-end-of-life evaluation, including emissions from energy production, manufacturing plants, and transportation.

- Blue water consumption, kg blue water

Blue water is measured as all water that is removed from the supply chain, including water lost to evaporation and water incorporated into the product.[19,20] Contaminated and noncontaminated water that is returned to the environment in acceptable condition for reuse is not counted as blue water. The life cycle of wastewater treatment is included for contaminated water.

- Solid waste generation, kg waste generated at point of use

Solid waste generation is the total solid waste generated at the healthcare facility derived from the isolation gowns and includes the gowns, biological waste on the gowns, and nonrecycled packaging.

RESULTS

The environmental evaluation of isolation gowns included the manufacture of gowns, manufacture of packaging, and landfill disposal of gowns and packaging (Table 3). The reusable gown system also included laundry operations. The disposable isolation gown system required 60 unique GTG LCIs that were added together to give the complete LCA. The reusable isolation gown system required 84 unique GTG LCIs. The environmental data from these LCIs were summed together for the disposable and reusable cases to calculate the 4 environmental indicators described in the Material and Methods section. For reporting purposes, the 144 life cycle inventories were grouped into 7 broad categories that illustrate the major activities of the product life cycle (Table 3 and Table 4). These 7 categories were classified into 3 groups: (1) gown and packaging manufacture and delivery, (2) end-of-life landfill disposable, and (3) laundry operations. The calculation of the environmental indicator results from the 7 categories is shown in Table 4.

Gown and packaging manufacture and delivery

The manufacture of isolation gowns and packaging included all activities from natural resource extraction through production of the final gown product. For purposes of the analysis, the reusable gowns were considered to weigh 240 g and were composed primarily of woven polyester, with a small amount of knit polyester used in the cuffs and a small amount of carbon fiber used as an antistatic agent. The disposable gowns were considered to weigh 63 g and were composed entirely of spunbond-meltblown-spunbond polypropylene fabric. LCI analysis found that the CTG manufacture of a single reusable isolation gown consumed about 68 MJ NRE/gown, whereas the CTG manufacture of a single disposable gown consumed about 5 MJ NRE/gown. This analysis included all activities from natural resource extraction through production and delivery of the final isolation gown. The increased energy for reusable gown manufacture was due to the weight difference, which is for the durability necessary for reuse and the increased energy requirement of woven textile operations compared to nonwoven textile operations. However, since reusable gowns were considered to be used 60 times before disposal, the energy consumption on a per-use basis was only 1.1 MJ NRE/gown use, representing a 77% decrease compared to disposable gowns.

The gown manufacture and delivery life cycle steps had a large influence on the environmental indicators for disposable isolation gowns, accounting for 97% of the energy consumption and global warming potential and 100% of the blue water consumption (Table 4). For reusable gowns, the gown manufacture and delivery steps accounted for only about 31% of the energy consumption and global warming potential and 80% of the blue water consumption, with laundry operations having a greater influence (Table 4).

The primary, secondary, and tertiary packaging used to deliver isolation gowns was primarily plastic bags and corrugated boxes.

Table 3
Comparison of reusable versus disposable systems for isolation gowns

LCI Component	Reusable gown architecture, per 1,000 uses	Disposable gown architecture, per 1,000 uses
Gown and packaging manufacture and delivery		
Manufacture and delivery of gown	4.00 kg gown manufactured and transported	63.0 kg gown manufactured and transported
Manufacture and delivery of packaging	0.703 kg manufactured; 109 kg transported *	10.1 kg manufactured and transported
End-of-life landfill		
Landfill of isolation gowns and packaging	0.413-4.41 kg landfilled †	63.2 kg landfilled
Landfill of biological waste	0-0.00323 kg landfilled †	0.194 kg landfilled
Laundry operations		
Laundry	240 kg gowns laundered	N/A
Water for laundry	2,640 kg metered water; 8.71 kg consumed (blue water)	N/A
Wastewater treatment to restore water	2,633 kg water treated	N/A

LCI, life cycle inventory.
*Reusable isolation gowns are transported in reusable carts or totes. The packaging material manufactured is lower than the packaging material transported with each gown use.
†Reusable gowns are sometimes reused in other industries, thus avoiding the landfill. The ranges represent the endpoint cases of and 100% reuse in other industries and 0% reuse in other industries.

Table 4
Environmental indicator calculations from life cycle inventory (LCI) components

LCI Component	NRE, MJ/ 1,000 uses		GWP, kg CO_2eq/ 1,000 uses		Blue water, kg/ 1,000 uses		Solid waste at hospital use site, kg/1,000 uses	
	Reusable	Disposable	Reusable	Disposable	Reusable	Disposable	Reusable	Disposable
Gown and packaging manufacture and delivery								
Manufacture and delivery of gown	1,133	4,996	68.6	300	35.1	74.6	–	–
Manufacture and delivery of packaging	16.7	120	1.03	6.95			–	–
End-of-life landfill								
Landfill of isolation gowns and packaging	2.43	34.9	0.139	1.99	0	0	0.413-4.41	63.2
Landfill of biological waste	–.0114	–0.682	0.0132	0.794	0	0	0-0.00323	0.194
Laundry operations								
Laundry	2,538	–	146	–	8.71	–	–	–
Water for laundry	7.31	–	0.411	–	0	–	–	–
Wastewater treatment to restore water	14.4	–	2.08	–	0	–	–	–
Total	**3,712**	**5,150**	**218**	**310**	**43.8**	**74.6**	**0.413-4.42***	**63.4**
Reduction from selecting reusable system, % of disposable system	**28%**	**–**	**30%**	**–**	**41%**	**–**	**93-99%**	**–**

CO_2eq, carbon dioxide equivalent; *GWP*, global warming potential; MJ, megajoueles; *NRE*, natural resource energy.
*The range represents the endpoint cases of 100% and 0% reuse in other industries.

The representative packaging materials and weights used in the study were based on measured samples of packaging of some of the gowns listed in Table 1 and Table 2. We found that about 18 g of packaging was required for each new reusable gown, and 10 g of packaging was required for each new disposable gown. In both cases, corrugated boxboard accounted for over 95% of the packaging weight requirements, with the remaining packaging being plastic and paper sheets. Wood pallets used to ship the gowns were considered to be recycled; thus, manufacturing of the pallets was not considered. However, the energy required to transport the pallets was considered. Similarly, reusable carts and totes used to transport reusable gowns to and from laundry were considered for transportation calculations. Overall, the packaging manufacture and delivery life cycle steps had only a 2%-3% impact on the environmental indicators (Table 4). This was because the weight of packaging used was relatively small compared to the weight of the gowns.

End-of-life landfill disposal

When gowns are used in healthcare facilities, a small amount of biological waste, such as human skin, is deposited on the gowns. In this study, the landfill process for reusable and disposable gowns included the collection, transportation, and processing of the gowns and biological waste at a landfill. The reusable and disposable gowns were considered to be non-degradable inert plastics. The biological waste on the gowns was considered to be processed as a degradable waste, with appropriate methane and CO_2 emissions included and a small energy credit shown for incineration of this gas at the landfill. The LCI for landfilling biological waste was based on several studies regarding the subject.[21-26]

Instead of being sent directly to a landfill, reusable isolation gowns may be reused in non-isolation applications at the end of the 60 isolation cycles. In life cycle practice, the environmental impacts of landfilling are attributed to the company that landfills the material. For complete transparency, end-of-life solid waste results for reusable gowns were given for the endpoint cases of 0% reuse and 100% reuse in other industries. Landfill operations had only a small impact on energy consumption, global warming potential, and blue water consumption (Table 4). However, the landfill was the endpoint for all of the solid waste generated from isolation gown use in healthcare facilities.

Laundry operations

A major difference in the life cycle of reusable and disposable isolation gowns is that reusable gowns are laundered before each use. The laundry process was evaluated based on field data collected in the International Association of Healthcare Textile Managers (IAHTM) 2016 annual survey.[27] The IAHTM data included annual median uses of water, natural gas, and electricity and were collected from 13 U.S. and 6 Canadian healthcare laundry companies, representing over 342 million annual pounds cleaned. The laundry operations included wash, rinse, and dry steps. The material inputs were gowns, water, and detergent, and the energy inputs were electricity and natural gas. Transportation of the gowns to and from the laundry operation was also included. The average round-trip transport distance was estimated as 70 miles.[15]

The energy consumption at a typical industrial laundry facility was found to be 6,750 MJ/1,000 kg textiles laundered. The primary form of energy use was natural gas, with utilities averaging 85% natural gas and 15% electricity.

Based on direct measurements at various laundry facilities, 99.7% of the water metered to the laundry process was considered to be returned by the municipality at acceptable levels for human exposure via a wastewater treatment plant. Wastewater treatment plant operations were included based on the chemical oxygen demand present in the wastewater from the laundry facility.[28] The evaporative losses of water from the dryer were included as a blue water impact.

The laundry operation life cycle steps had a large influence on the environmental indicators for reusable isolation gowns, accounting for 68% of energy consumption, 67% of greenhouse gas emissions, and 20% of blue water consumption (Table 4). However, the environmental savings realized from manufacturing fewer gowns more than offset the additional burden of the laundry process (Table 4).

Summary

In the cradle-to-end-of-life evaluation of reusable and disposable isolation gowns, selecting the reusable gown system resulted in a 28% reduction in NRE consumption, a 30% reduction in global warming potential, a 41% reduction in blue water consumption, and a 93%-99% reduction in solid waste generation at the healthcare facility compared to selecting the disposable gown system (Table 4).

The blue water savings for reusable gowns was slightly larger than the energy savings (Table 4). Most blue water use for both reusable and disposable gowns was due to evaporative losses in the industrial cooling systems during the CTG manufacture of the gowns. The laundry process did not have a cooling water need. The evaporative losses from the laundry step were lower than the evaporative losses from the cooling systems used for disposable gown manufacture, which led to a large savings in blue water.

DISCUSSION

Reusable isolation gowns outperformed disposable isolation gowns in all 4 environmental indicators studied. The reduction in all categories was due to the large impact of the gown manufacturing and delivery life cycle steps, particularly for the disposable gowns (Table 4).

The environmental results for the disposable isolation gown were highly dependent on the weight of the gown. A 10% decrease in the weight of the disposable gown resulted in an approximately 10% decrease in all 4 impact categories. If the weight of the disposable gown was reduced from 63 g to about 45 g, the energy consumption and global warming potential for the disposable and reusable isolation gowns would be about even. Of the 16 disposable isolation gowns examined, only 1 was below the 45-g threshold. The weight of the reusable gown was much less important: a 10% decrease in reusable gown weight resulted in only about a 3% decrease in the 4 environmental impact categories.

The environmental results for the reusable isolation gown were highly dependent on the efficiency of the laundry process. A 10% decrease in laundry energy consumption resulted in an approximately 7% decrease in energy consumption and global warming potential. Midpoint values were used for the energy consumption at industrial laundry facilities. In the blue water analysis, 0.3% of the water metered to the industrial laundry facility was considered to be lost to the environment as blue water. The blue water calculation for reusable gowns was dependent on the amount of moisture on the gowns entering the drying process, since the water was evaporated and lost to the environment upon drying.

CONCLUSIONS

In a comprehensive life cycle evaluation of isolation gowns, 7 components were analyzed as LCIs for reusable and disposable gowns (Table 3). The components were linked and combined according to mass flows. The environmental footprints from cradle-to end-of-life were documented (Table 4).

The reusable isolation gown system consumed 28% less energy and emitted 30% less greenhouse gasses compared to the disposable isolation gown system. Water consumption for the reusable gown system was found to be about half that of the disposable gown system. This result is contrary to common perceptions, which designate reusable garments as more water intensive due to the laundry step. The public perception often fails to consider the water consumed in the disposable gown supply chain and does not consider the principle of water footprint that designates blue water as the best consumption principle. The solid waste generation at the healthcare facility for the reusable isolation gown system was found to be significantly lower (93%-99%) than for the disposable gown system. This range was a result of 2 different scenarios for end-of-life management of the reusable gowns.

Sensitivity analysis showed that the results are robust and unlikely to change based on expected variations from product to product. This analysis, combined with agreement of previous partial life cycle studies of other medical textiles, makes it absolutely clear that the environmental benefit of reusable isolation gowns is significant.[10-12] The environmental improvements have been quantified herein and can be used by healthcare facilities for their achievements in sustainability programs.

There would appear to be increased environmental benefits for any textile items that are reusable versus disposable. Thus, adding the life cycle of other textile and non-textile items found in healthcare facilities, such as gloves, wipes, or masks, would further strengthen the environmental benefits of reusable systems.

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