LIFE CYCLE ASSESSMENTS OF SINGLE- VERSUS MULTIPLE-USE SURGICAL GOWNS

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ABSTRACT

A comparative life cycle assessment (LCA) is a tool that can be used to compare two functionally equivalent products' environmental impacts. This paper reports on cradle to grave comparative LCA for single use/disposable and multiple-use/washable surgical gowns. This LCA is specific for surgical gowns used in the Twin Cities of Minneapolis and St Paul, Minnesota. Chain Management by Life Cycle Assessment (CMLCA) software has been used to conduct the LCA and Ecoinvent 2.01 has been used for life cycle inventory data. The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) life cycle impact assessment methodology has been applied. Nine factors have been compared in this work: three related to human health; carcinogens, non-carcinogens, respiratory effects and six related to the environment; acidification, ecotoxicity, eutrophication, global warming, ozone depletion and photochemical oxidation. The International Standards Organization (ISO) 14044 serves as the guide for the LCA methodology and interpretation. The geographical scope reflects data and transportation from Asia to North America. Fifty surgeries represents the functional unit on which the gown types were compared. The single use gown shows the highest overall values for the impact categories primarily attributable to the repeated manufacture, transportation, and disposal of fifty gowns while the multiple-use gown has higher impact primarily associated with laundering fifty times. The single use gowns have higher impacts for carcinogens, non-carcinogens, respiratory effects, acidification, eutrophication, global warming, and photochemical oxidation. Multiple-use gowns have higher impacts for ecotoxicity and ozone depletion.

INTRODUCTION

Forty years ago healthcare facilities utilized many reusable products. Everything from china to washbasins, surgical instruments and gowns were washed and if necessary, sterilized for reuse. With the advent of blood borne diseases such as Hepatitis and HIV-AIDS concerns about transmission to healthcare workers and patients increased. Numerous healthcare related products were converted to single use, disposable items. Healthcare facilities are now reconsidering the sustainability of single use items, often comprised of petroleum based plastics. Some of these items are now being safely reprocessed for reuse, saving resources. It is with similar thinking healthcare facilities are now deliberating the appropriateness of multiple-use surgical gowns.

Healthcare facilities have many considerations when choosing protective clothing for surgical staff. The gowns must adequately cover body areas that may be exposed to splashes, sprays and spills of body fluids. The fabrics must be relatively impervious to body fluids for relatively long periods of time, while simultaneously providing ventilation. The gowns must be reasonably priced. If the gowns are to be laundered for reuse, they must be able to retain their protective capacity through at least 50 wash cycles and the laundering costs must be reasonable. Single use disposable gowns must have the same attributes as multiple-use gowns, but because they are not reusable and must be replaced for each use, they must be reasonably priced as a large healthcare facility may dispose of millions of gowns on an annual basis. As concern over the environment increases, healthcare facilities, as part of their missions to support community health and make wise use of resources, are looking for products that are environmentally preferable and cost effective.

A comparative life cycle assessment (LCA) is an analytic tool that can be used to evaluate differing materials' environmental performance. As society struggles to identify those products that are more sustainable, LCA can assist with discerning those products that are environmentally preferable through quantitative comparison. In industries such as healthcare, that are trying to determine which products are environmentally preferable, LCA can be used for product selection and product development by manufacturers. LCA considers products beyond their physical attributes and usefulness during the stages throughout their existence.

Generally products that are multiple-use have been viewed favorably with respect to environmental impacts and energy use. However calculation of impacts depends on system and boundary conditions considered during the study. Three boundary conditions are typically analyzed in Life Cycle Assessments. Cradle-to-gate LCA starts with the extraction of raw material and ends when the finished product leaves the factory gate. A cradle-to-grave LCA ranges from the extraction of raw materials used for manufacturing of products through disposal of the product in landfill, incineration or recycling. A cradle-to-cradle study considers the product lifecycle from the extraction of raw materials through disposal and beyond, - considering energy recovery from incineration or raw material replacement when reuse of the products occurs. (Madival, 2009). The work reported here compares surgical gowns from a cradle to grave boundary system

The questions about the sustainability of multiple-use versus single use, disposable gowns has centered on whether the environmental impacts are greater with laundering a gown 50 - 70 times as opposed to manufacturing and disposing of an equivalent number of single-use gowns. This LCA has been designed to try and answer these questions.

GOAL, SCOPE AND METHODS

Goal

The goal of this study is to compare the environmental impacts of polypropylene (PP) single-use, disposable surgical gowns with polyethylene terephthalate (PET) multiple-use surgical gowns.

Scope

This study has been designed as a cradle-to-grave evaluation. Two comparative LCA have been conducted. Each starts with the manufacture of the plastic resin raw materials through the manufacture of fabric, cutting and sewing of the gowns, use and laundering for the multiple-use gowns and final disposal by incineration of both gowns. The scope included consideration of human health and environmental impacts as identified in TRACI; carcinogens, non-carcinogens, respiratory effects, acidification, ecotoxicity, eutrophication, global warming, ozone depletion and photochemical oxidation. The functional unit was chosen as 50 surgical procedures. Fifty wash cycles is considered the life of a PET multiple-use gown. Fifty single use PP gowns are used and disposed, for each multiple-use gown used and laundered.

Methods

The framework for the LCA has been defined according to the International Standards Organization (ISO) 14040 and 14044 guidelines (ISO 14040, 14044). This includes the goal and scope definition of the problem and structure of the inventory analysis. The LCA and interpretation have been guided by ISO 14044. CMLCA (Leiden University) software has been used to conduct the LCA. Ecoinvent 2.01database contains life cycle inventory data (raw data and results) of more than 4000 industrial processes, products and services and has been used as the primary data source for the inventory analysis. TRACI life cycle impact assessment methodology has been used for environmental impacts and normalization of the results.

SYSTEM BOUNDARIES

Table 1 provides a summary of the system considerations for this analysis for both multi-use and single-use surgical gowns. These considerations include process impacts from both polymer and gown production, transportation, use and end of life

Table 1 – System Considerations

	Disposable PP Gown	Multiple Use PET Gown
Raw Material	Petroleum Based	Petroleum Based
Process Impacts	PP Production PP Extruded Film Production Gown Production	PET Production PET Fiber/Fabric Production Gown Production
Transportation	China to Hospital Hospital to Disposal	US Producer to Hospital Hospital/Laundry round trip (50) Hospital to Disposal
Times Through Process	50	1

Polymer Production

The Ecoinvent database aggregates data for all processes from raw material extraction until delivery at the plant for polypropylene (PP) production. Not included are the values reported for: recyclable wastes, amount of air, nitrogen and oxygen consumed, unspecified metal emissions to air and to water, mercaptan emission to air, unspecified chlorofluorocarbon/hydrochloroflourcarbon (CFC/HCFC) emissions to air and dioxin emissions to water. The amount of "sulfur (bonded)" is assumed to be included into the amount of raw oil (Ecoinvent, 2007). For polyethylene terephthalate (PET) production, ethylene glycol and purified terephthalic acid (PTA) are ultimately converted to the granulate resin. The Ecoinvent data includes material and energy input, and waste as well as air and water emissions. Summary parameters for dissolved organic carbon and total organic carbon are not included and data for transport and infrastructure are estimated (Ecoinvent, 2007).

Garment Production and Transport

The PP is extruded into plastic film, cut and sewn into gowns and then transported from Souzhou, China to the coast and sent via transoceanic freighter to the United States. The gowns are then sent via rail to Chicago, Illinois and trucked for distribution in Minnesota. The PET resin is extruded into yarn and ultimately woven into fabric. The PET fabric is manufactured in a number of locations. According to industry representatives many the sources are confidential. The preferred source is in Alabama, United States (Bushman, 2010). Most of the PET multiple-use gowns are cut and sewn in Alabama then trucked to Minneapolis/St. Paul, Minnesota for use.

Gown Use and Disposal

When the gowns are delivered for use at the healthcare facility, they may be packaged and/or sterile. The gown packaging regimes are variable and the database did not contain information regarding sterilization. Both of these flows were omitted in the LCA. After use the disposable PP gowns are trucked to a municipal solid waste incinerator and the multiple-use **PET** gowns are trucked to the laundry. Both facilities are in the Minneapolis/St. Paul metropolitan area.

DATA AND DATA QUALITY

Information regarding the gowns' composition, weight, manufacturing and distribution locations was obtained from their respective manufacturers; Cardinal Health (Holguin, 2010) for disposable PP and Standard Textile (Bushman, 2010) for the multiple-use PET gowns. Both gowns are constructed to the Association for the Advancement of Medical Instruments (AAMI) Level 3 barrier protection. Data for inputs associated with laundering the PET gown, detergent, energy and water, came from the detergent manufacturer and Health System Cooperative Laundries in St. Paul, Minnesota (Hilton, Tinker, 2010). Fifty surgeries is the functional unit. Impact assessment data was obtained from Ecoinvent 2.01 (2007). Specifics for each step are discussed below.

Resin production

The finished gown weights; 136 grams for PP, and 386 grams for PET were used to quantify the portion of each process associated with each gown. One percent of the PP fabric and 5% of the PET fabric is lost during sewing and assembly (Holguin, Bushman, 2010). To determine the weight of resin needed for each gown, the weight of the finished gowns plus the amount wasted was used. For the PP gown, 137.374 grams of PP is needed for each gown. Resin production losses are 0.023 grams per kilogram. The final weight of PP resin needed per gown is 140.752 grams.

For the PET gown 5% loss from resin production is typical (Bushman, 2010). The final weight of resin needed was determined to be 428.212 grams.

The data for the PP and PET resin manufacturing are from the Eco-profiles of the European plastics industry (Ecoinvent, 2007). It was assumed the manufacturing processes and hence data are essentially similar worldwide. The data include material and energy input, waste as well as air and water emissions.

Not included in the Eco-profiles are the values for: recyclable wastes, amount of air/nitrogen/oxygen consumed, unspecified metal emissions to air and water, mercaptan emissions to air, unspecified chlorofluorocarbon/hydrochloroflourcarbon (CFC/HCFC) emissions to air and dioxin to water. The amount of bonded sulfur was assumed to be included into the amount of raw oil (Ecoinvent, 2007).

The data was averaged for the production of amorphous PET out of ethylene glycol and purified terephthalic acid (PTA). Missing were summary parameters for dissolved organic carbon (DOC) and total organic carbon (TOC). Transportation and infrastructure were estimated (Ecoinvent, 2007).

Manufacture of fabrics

The Ecoinvent database provides extrusion impacts for plastics in general; no specific data for PP and PET resins is available. PP is extruded into plastic film. The process data contains the auxiliaries and energy demand for the conversion process. The converted amount of plastics is not included into the dataset (Ecoinvent, 2007).

PET is extruded into yarn. As with PP, no specific data is provided for conversion of the PET yarn into fabric. However, conversion to fleece is available and includes an estimation of electricity and fuel use. This was assumed to be a comparable process. No raw materials and transports of raw materials to the plant or infrastructure of the production facility were included (Ecoinvent, 2007). Manufacture of the PET yarn into fabric and cutting and sewing of the gown is usually accomplished at the same facility in Enterprise, Alabama (Bushman, 2010).

Gown manufacture

The Ecoinvent database does not contain information on the processes related to gown manufacture, e.g. cutting, piecing and construction. The processes in gown construction appear to be similar for both the PP and PET gowns (King, 1985); it was assumed the relative impact contributions to be essentially similar. This flow was omitted in the LCA.

DISTANCES AND TRANSPORTATION

Single-use PP gowns

The disposable gowns are manufactured in Souzhou, China and then transported by truck to a shipping port in Shanghai, China. Land transportation was assumed to be carried out by 20-28 ton trucks. The distance is 801 kilometers. The gowns are then transported 11,670 km by ocean freighter to Long Beach, California. From the Long Beach distribution center the gowns are shipped 2810 km via rail to Chicago, Illinois. Transportation from Chicago to the distribution center in Champlin, Minnesota and ultimately the user facility in Minneapolis Minnesota, for a total of 446 km is accomplished by truck. Facility locations and transportation modes were provided by Cardinal Health (Holguin, 2010). Distances were determined by Google Maps.

The impacts for transportation were obtained from the Ecoinvent database. For truck transportation the inventory refers to the entire transport life cycle and includes operation of the vehicle; production, maintenance and disposal; and, construction, maintenance and disposal of the roads. Data represents generic European processes, save for vehicle disposal, which is based on Swiss processes.

Transoceanic freight shipment impacts include the entire transport life cycle; production and operation of the vessel using steam turbines and diesel engines and, construction, land use, operation, maintenance and disposal of 2 ports.

Railway freight transport includes operation of diesel trains only. The inventory is based on United States geography extrapolated from European data. This dataset includes production, operation, maintenance and disposal of vehicles; and construction, mmaintenance and disposal of railway tracks.

Multiple-use PET gowns

According to Standard Textile, the manufacture of fabric and sewing of the gowns most frequently occurs at their Enterprise, Alabama facility (Bushman, 2010). From the manufacturing facility in Alabama to the laundry in St. Paul, Minnesota is a distance of 1997 km. The gowns are transported by truck. From the laundry to the user facility in Minneapolis, Minnesota the distance is 15 km, and transportation is assumed to be by 3.5-20 ton truck.

CONSUMPTION AND DISPOSAL

Single-use PP Gown

The disposable polypropylene gown is used once and then disposed of. In the Minneapolis/St Paul area, waste is incinerated at waste-to-energy facilities. In this instance, the incinerator is located approximately 8 km from the user facility. The inventory for this flow included the use of a 3.5-20 ton truck. The Ecoinvent database was used.

Multiple-Use PET Gown

After use the PET gowns are transported to the laundry where they are washed, dried, inspected for quality and returned to the user facility. For each gown laundered 0.937 g of 50% sodium hydroxide, 0.2556 g of 100% linear alcohol ethoxylate non-ionic surfactant and 100% granular complex phosphates and 0.835 g of 35% hydrogen peroxide is used (Tinker, 2010). For utilities, 0.037 kilowatt hour of electricity, 1.58 Milli Joule (mJ) natural gas, and 2.42 kg of water is used. Water is reused in the wash process. For the purpose of this LCA, after 50 wash cycles the gowns were disposed of via incineration. In the real life scenario, end of life PET gowns are down-cycled into rags.

ALLOCATION

The allocation procedure is necessary for processes that yield more than one product. For this study no additional products were manufactured hence no allocation is needed.

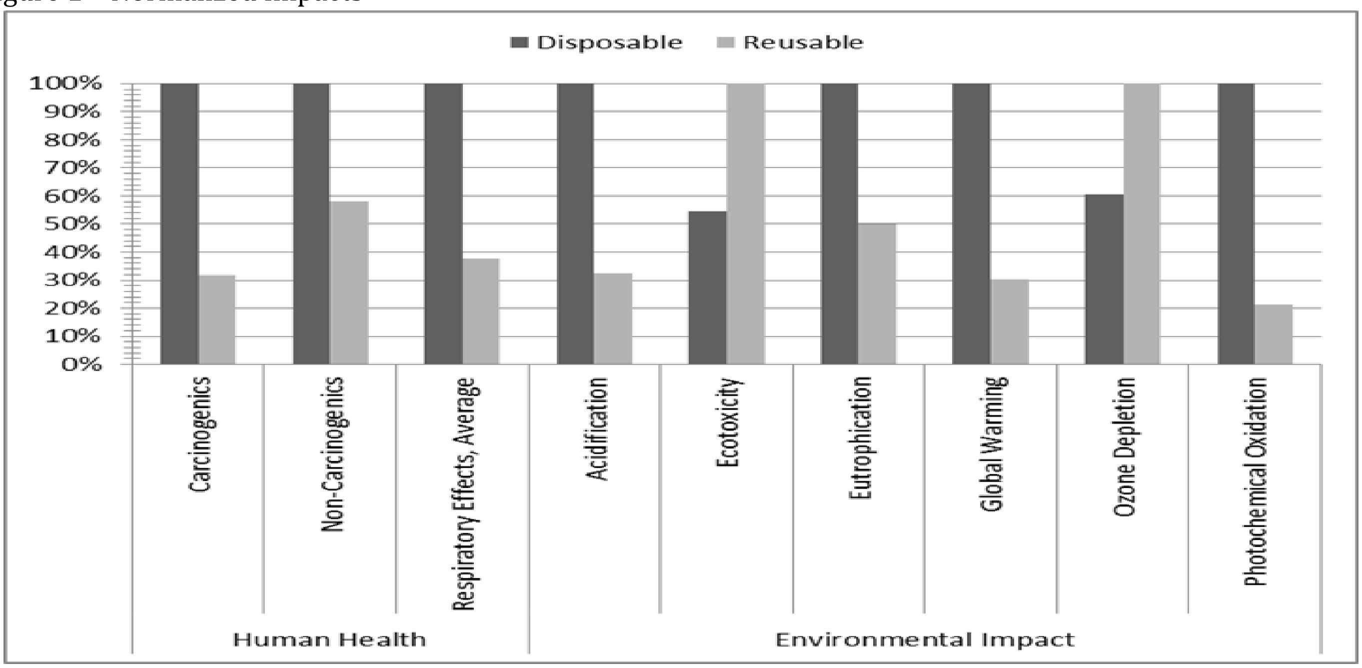
IMPACT ASSESSMENT

TRACI life cycle impact assessment methodology was used. TRACI was developed by the U.S. Environmental Protection Agency. It was chosen due to its ability to quantify environmental and human health impacts. TRACI converts the life cycle inventory data into impact categories using reference units[1]. The environmental impact categories considered are; acidification, ecotoxicity, eutrophication, global warming, ozone depletion and photochemical oxidation. The human health impact categories are; carcinogens, non-carcinogens and respiratory effects.

RESULTS AND DISCUSSION

Figure 1 shows the normalized impacts comparing 50 single-use PP gowns and one multiple use PET gown laundered 50 times. The single-use PP gown has the higher impact across most categories, carcinogens, non-carcinogens, respiratory effects, acidification, eutrophication, global warming and photochemical oxidation. The multiple use PET gowns have more impacts associated with ecotoxicity and photochemical oxidation. Tables 2 (single-use PP gowns) and 3 (multiple-use PET gowns) list the process contributions to the impact categories. For ease of discussion and comparison, the processes have been combined into "Manufacturing", "Transportation", "Washing" and "Disposal". The results are discussed in more detail below.

Figure 1 – Normalized Impacts



[1] Impact categories: Environmental: Acidification is defined as the potential to cause wet or dry acid deposition and is expressed as moles of hydrogen ion equivalents, H+-Eq. Ecotoxicity is defined as the potential of a chemical released into an evaluative environment to cause ecological harm and is expressed in kilograms of 2, 4- D, a chlorinated and toxic pesticide, kg 2, 4-D-Eq. Eutrophication is defined as the potential to cause eutrophication and is expressed in kilograms of nitrogen, kg N. Global warming is defined as the potential global warming based on chemical's radiative forcing and lifetime. It is expressed as kilograms of carbon dioxide equivalent, kg CO2-Eq. Ozone depletion is defined as potential to destroy ozone based on chemical's reactivity and lifetime and is expressed as kilograms of chlorofluorocarbon-11 equivalent, kg CFC-11-Eq. Photochemical oxidation is defined as the potential to cause photochemical smog and is defined as kilograms nitrogen oxide equivalents, kg NOx-Eq. Human health impacts: Carcinogens are the potential of a chemical released into an evaluative environment to cause human cancer effects and are expressed as kilograms of benzene, a known human carcinogen, expressed as, kg benzene-Eq. Non-carcinogens are defined as the potential of a chemical released into an evaluative environment to cause human non-cancer effects. They are expressed as kilograms toluene equivalent, kg toluene-Eq. Respiratory effects are defined as exposure to elevated particulate matter less than 2.5 micrometers, and are expressed as PM2.5-Eq.

Tables 2 and 3: The impact assessment values for 50 single-use PP gowns and one multiple use PET gown laundered 50 times. The values are for cradle-to-grave analysis carried out for 9 impact categories using EPA's TRACI tool.

Table 2: SINGLE USE PP GOWNS						
	Impact Category	**Manufacturing**	**Transportation**	**Washing**	**Disposal**	**Units**
Human Health	Carcinogens	4.285E-03	2.478E-03	0	1.757E-02	kg benzene-Eq
	Non-Carcinogens	1.344E+01	7.492E+00	0	1.885E+01	kg toluene-Eq
	Respiratory Effects, Average	1.180E-02	5.760E-03	0	2.852E-04	kg PM2.5-Eq
Environmental	Acidification	3.008E+00	1.980E+00	0	1.381E-01	moles of H+Eq
	Ecotoxicity	7.578E-01	4.324E-01	0	4.493E-02	kg 2,4-D-Eq
	Eutrophication	4.006E-03	2.227E-03	0	2.134E-04	kg N
	Global Warming	1.723E+01	2.860E+00	0	1.731E+01	kg CO2-Eq
	Ozone Depletion	1.850E-07	3.733E-07	0	2.066E-08	kg CFC-11-Eq
	Photochemical Oxidation	2.960E-02	3.270E-02	0	3.091E-03	kg NOx-Eq

Table 3: MULTIPLE USE PET GOWN						
	Impact Category	**Manufacturing**	**Transportation**	**Washing**	**Disposal**	**Units**
Human Health	Carcinogens	3.573E-03	9.187E-05	3.073E-03	1.014E-03	kg benzene-Eq
	Non-Carcinogens	1.120E+01	4.708E-01	1.026E+01	1.144E+00	kg toluene-Eq
	Respiratory Effects, Average	3.092E-03	1.466E-04	3.473E-03	1.904E-05	kg PM2.5-Eq
Environmental	Acidification	6.886E-01	5.862E-02	8.974E-01	1.059E-02	moles of H+Eq
	Ecotoxicity	7.253E-01	2.107E-02	1.517E+00	2.580E-03	kg 2,4-D-Eq
	Eutrophication	2.640E-03	8.852E-05	4.779E-04	2.116E-05	kg N
	Global Warming	3.384E+00	1.493E-01	7.014E+00	7.898E-01	kg CO2-Eq
	Ozone Depletion	1.820E-07	2.405E-08	7.510E-07	1.266E-09	kg CFC-11-Eq
	Photochemical Oxidation	5.453E-03	1.288E-03	6.944E-03	2.410E-04	kg NOx-Eq

<u>Human health effects</u>

Carcinogens

Disposal of the PP gowns represents the greatest impact category at 72% of total emissions. As suggested by Figure 1, carcinogenic impacts for the PP gowns are almost an order of magnitude higher than for PET, 0.024 kg benzene-Eq vs. 0.001 kg benzene-Eq. The primary carcinogen impacts for PET gowns are in the washing and manufacture with both processes being fairly small at approximately 0.003 kg benzene-Eq.

Non-carcinogens

The PP gowns had the highest of non-carcinogen impacts at 39.8 kg toluene-Eq. Manufacture represented 34% and disposal 47%. The PET gown total is equal to 23.1 kg toluene-Eq with almost equal contributions due to manufacture 49% and laundering 44%.

Respiratory effects

Manufacture of the PP gowns represented 66% (0.012 kg PM-Eq) of the impact in this category. Transportation added another 32% (0.006 kg PM-Eq) for a total of 98% of the respiratory effect impacts of the PP gowns. The PET gowns' overall impact was 38% of PP, with manufacture accounting for 46% (0.003 kg PM-Eq) and laundering 52% (0.003 kg PM-Eq).

Environmental Impacts

Acidification

The manufacture and transportation of the single use PP gowns accounted for 97% of the 5.12 moles [H+]-Eq. The PP gowns total moles [H+]-Eq exceeds the acidification impacts of the PET gowns by 3.47. Laundering accounted for 54% of PET gowns' 1.66 moles [H+]-Eq, with manufacturing making up 42%.

Ecotoxicity

The kg 2, 4, D-Eq associated with manufacturing are essentially equal for both gowns, PP = 0.756 and PET = 0.725. The process with the highest ecotoxic impact is laundering of the PET gowns at 1.52 kg 2, 4, D-Eq. Manufacture and transportation accounts for 96% of the PP gowns ecotoxicity impacts.

Eutrophication

Manufacture of the PP gown was the single highest contributor to eutrophication at 0.004 kg N. Overall the PP gowns accounted for twice as much eutrophication than the PET gowns, the primary impact areas being manufacture and transportation.

Global warming

The disposal of the PP gowns accounts for 46% of its kg CO2-Eq. PP gown manufacturing makes up another 46% with the two processes accounting for 92% of PP's total global warming impacts equal to 37.4 kg CO2-Eq. The total CO2-Eq for the multiple use PET gowns is equal to 11.34 with manufacture equal to 3.384, laundering 7.014 and transportation 0.149.

Ozone depletion

Laundering of the PET gowns was the biggest impact in this category, equal to 7.51E-07 kg CFC11 Eq. For the PP gowns, the large transportation distances coupled with manufacturing processes comprised 96% of its CFC 11 Eq. The manufacturing impacts for both gowns were equal at 1.84E-07 kg CFC 11 Eq.

Photochemical oxidation

Transportation-related kg NOx-Eq slightly edged manufacturing NOx associated with the PP gowns, 50% vs. 45%. The sum of the PET processes, 0.013 kg NOx-Eq comprised only 21% of the total PP photochemical oxidation impacts, 0.066 kg NOx-Eq.

LIMITATIONS AND ASSUMPTIONS

System boundaries

Resin Production

The PP and PET resin production was based on European processes and did not include local transportation. No specific data for extrusion of PP or PET was provided. We assumed the extrusion data for the 2 polymers to be similar to that of plastic film. PP resin can be extruded directly as a plastic film; hence the Ecoinvent general data was used. PET can be extruded as fiber and woven into fabric. This process was not available in the Ecoinvent database. PET fleece production was assumed to be similar and was the process included in lieu of fiber weaving.

Gown construction

No data was available for the cutting, piecing and sewing of the 2 gowns. The PET gowns are sewn together from a number of pieces some of which are double fabric thickness. This is to increase the durability and comfort of the gowns. The PP gowns are reinforced in the front and sleeves, which adds to gown complexity and possibly an increase in pieces used. However, no information was available regarding the construction of the PP gowns. The energy for these processes was assumed to be similar.

Dyes

Both gowns are colored and appear to contain dyes. Dyes and many other chemicals have environmental and public health impacts not often considered in LCA (Beck, 2000). Ecoinvent did not contain a process for the dying of textiles. No data or information on dyes was received from the manufacturers. It was assumed the dyeing process was essentially equal for both.

Packaging

The surgical gowns can be packaged singly or in multiple item packs. The packaging regime for single use PP surgical gowns can consist of a clear plastic outer wrap and then blue PP wrap which protects the gown after sterilization. Multiple use PET gowns in small packs are packaged in a PP wrapper; if the packs contain a number of gowns, a reusable polyester wrap is used to envelop the gowns (Fordyce, 2011).

Sterilization

Sterilization is a key component of surgical gown management and use. It can be accomplished using ethylene oxide, hydrogen peroxide plasma or water-based steam. The Ecoinvent database did not contain sterilization processes and this flow was omitted from the LCA.

FINAL REMARKS

This work evaluated the environmental and public health impacts of single use PP and multiple use PET surgical gowns used for 50 surgeries. The PP gowns contributed the most in the impact categories: disposal via incineration contributed most to carcinogens, non-carcinogens and global warming;

transportation contributed most to eutrophication, ozone depletion and photochemical oxidation; manufacturing contributed most to acidification, eutrophication and global warming.

The impacts associated with the PET gowns are primarily attributable to the laundering process and were the highest for ecotoxicity and ozone depletion.

No weighting of the relative impacts was performed as part of the LCA. However, impacts could be reduced for the PP gowns by minimizing transportation distances between manufacturers and users. For the PET gowns, the ecotoxicity and ozone depletion possibly could be reduced with less toxic laundering chemicals. Patagonia, an outdoor clothing company uses PET from clear plastic bottles to manufacture some of its products. This may be another way for the PET gowns to reduce ecotoxicity and eutrophication impacts. Use of recycled PP may reduce the acidification, eutrophication and global warming impacts for the single use gowns.

The European Union's REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals) regulations require clothing manufacturers to disclose the chemicals used in their products. Tesco, a large British retailer is looking to label every product it sells based on its carbon footprint (Claudio, 2007). The world's largest retailer, Wal-Mart has incorporated sustainability criteria into its procurement and construction standards. As more healthcare facilities work on sustainability initiatives, they, too, are looking for products with less environmental impacts. This study provides evidence that overall, PET multiple use gowns have less environmental and public health impacts than single use PP gowns.

Acknowledgements

The authors thank Fairview University Medical Center for their interest and support of this study. We also thank Cardinal Health, Health System Cooperative Laundries and Standard Textile for providing data for the LCA. Thank you to the American Reusable Textile Association for financial support to write this article.

References

Bare, J., Norris, G., Pennington, D., McKone, T., TRACI: the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts, J Ind Eco, 2003, 6:3.

Beck, A., Scheringer, M., Hungerbuhler, K., Fate Modeling within LCA: The Case of Textile Chemicals, Int J LCA 5:6 (335-344), 2000.

Brower, M., Leon, W., Three Rivers Press, The Consumer's Guide to Effective Environmental Choices, 1999.

Bushman, B. Standard Textile, E-mail conversation, March 2010.

Carre, A., Life Cycle Assessment Comparing Laundered Surgical Gowns with Polypropylene Based Disposable Gowns, RMIT University, Centre for Design, 2008.

Claudio, L., Waste Couture: Environmental Impact of the Clothing Industry, Environ Health Prospect 115: A449-A454, 2007.

Ecoinvent Data version 2.01, Swiss Centre for Life Cycle Inventories, CD-ROM, 2007.

Fordyce, B., Health Systems Cooperative Laundries, E-mail conversation, March 2011.

Google Maps, maps.google.com, 2010.

Hilton, Larry, Healthcare Cooperative Laundries, personal conversation, March 2010.

Holguin, M., ICA Market Manager, Cardinal Health E-mail conversation, January 2010.

International Standards Organization, ISO 14040 Environmental management-life cycle assessment-principles and framework, 2nd Edition, 2006.

International Standards Organization, ISO 14044 Environmental management-life cycle assessment-requirements and guidelines, 1st edition, 2006.

Leiden University, Institute of Environmental Sciences, Chain Management by Life Cycle Assessment: Scientific Software for LCA, available at http://www.cmlca.eu/, 2010.

Madival, S., Aurus, R., Singh, P.S., Narayan, R., Assessment of the environmental profile of PLA, PET and PS clamshell containers using LCA methodology, J Clean Prod 17 (2009) 1183-1194.

Nigam, P., SIE project, Study of the polyester garment production process: LCA and screening, Ecole Polytechnic Federale de Lausanne, 2007.

Tinker, S., Vice President, Gurtler Industries, E-mail conversation, March 2010.

Woolridge, A., et al, Life Cycle Assessment for reuse/recycling of donated waste textiles compared to use of virgin material: a UK energy saving perspective, Resources, Conservation and Recycling 46:194-103, 2006.