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Phoenix Medical Waste Disposal LCA

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Executive Summary

Background, aim, and scope: Biohazardous medical waste (BMW) is treated primarily by two methods in the United States: autoclave sterilization and incineration. According to the World Health Organization (2011), the majority of a hospital's waste, 75-90%, is non-infectious waste, meaning it can be treated as general municipal solid waste (MSW). The remaining 10-25% is considered hazardous, because it is either radioactive, toxic, or infectious. Due to this criteria, BMW does not follow the general options of reduce, reuse, and recycle. Rather the key priority of BMW is to ensure that only medical waste that fits the definition of BMW is treated as such, which requires proper waste segregation in every corner of the hospital, accompanied with the proper educational training, and supervision of the waste management program to ensure compliance. This life cycle assessment (LCA) can be used to demonstrate why BMW reduction is important, which is possible primarily by diverting more MSW out of the BMW stream, as well as other BMW reduction strategies.

This study aims to quantify the environmental impacts of a hospital's daily BMW disposal in the Phoenix, Arizona area. The sole option to dispose of BMW in Arizona is to sterilize the waste by sending it through an autoclave, and then dispose the sterilized waste in a landfill. This study used a Phoenix area hospital to create a start point for the waste and a general estimation of how much BMW the hospital disposes of. The system boundary for the LCA includes BMW generated at the Phoenix-area Hospital as it is travels to Stericycle, where it is autoclaved, and then transported to a landfill for disposal. The results of this retrospective, end-of-life LCA using this boundary enables hospital employees and policy makers to understand the environmental impact of placing items in the biohazardous waste bin.

Methods and Materials: Methods and techniques outlined in the International Organization for Standardization (ISO) number 14040 and 14044 are used as the basis of this analysis. The functional unit in this study is kilograms of BMW produced daily and disposed of to the U.S. Environmental Protection Agency's (EPAs) standard for autoclave. Data were obtained using ecoinvent output of ReCiPe midpoint indicators and the EPA WARM model. Two scenarios were compared in this attributional LCA: (1) the environmental impacts of the "business-as-usual" case, where it is assumed that 50% of all hospital waste is sterilized, even if it is not biohazardous and (2) and the impacts in the ideal case, when only true BMW is sterilized, which is about 16% of the hospital's waste.

Results: To understand the impacts of fossil fuel resource depletion, climate change, and human toxicity generated by the disposal of biohazardous medical waste (BMW), ReCiPe Midpoint (E) impacts were collected for global warming depletion (GWP500), fossil fuel depletion potential (FDP), and human toxicity potential (HTPinf). Based on the assumptions made during the LCA process, overall, the ideal scenario showed significantly less of an environmental impact than the business-as-usual (BAU) case. Our results show the greatest impact on global warming potential was transportation, and the greatest fossil fuel depletion human toxicity potential occurred in the landfill. However, during the autoclave process water is steamed out of the waste materials, resulting in a 30% reduction of the weight. This weight reduction means that the ideal case load on the landfill is greater, and thus, creates more waste to move around and decompose. This results in higher fossil fuel depletion potential and human toxicity potential. This contradiction in our overall statement that the ideal situation has a higher impact in the landfill process is a result of our system boundary, because wastewater treatment was not taken into account, and therefore, we can assume fossil fuel depletion and human toxicity potential would be higher in the business-as-usual case, when more waste in autoclaved.

Sensitivity and Uncertainty: This study includes a disclosure of our assumptions, data quality, and temporal and geographic variations in data quality by including a data quality assessment using a pedigree matrix. This assessment highlights hotspot areas where future research could be conducted for data quality improvement.

Discussion: Ideally, if a hospital were to change their business-as-usual waste management practices, recycling and reduction practices would also be incorporated into a more sustainable waste management program. Recycling and reducing waste would decrease the amount of waste that would go to the landfill, which this study shows is the source of the highest fossil fuel depletion and human toxicity potential in the end-of-life analysis. Many strategies can be used to reduce and recycle waste in hospitals, such as commingled recycling across the hospital including the operating rooms, reusable options such as hard sterile cases instead of one use medical wrap, and reprocessing medical instruments. This LCA can be used as a tool to influence and educate policy makers and health care practitioners on the impacts of global warming potential, fossil fuel depletion, and human toxicity potential when autoclave sterilization is used to treat BMW.

Introduction

Illegal dumping of medical waste was brought to public attention in the mid-1980's when several disturbing events made headlines in the national media. Approximately 1,400 bags of medical waste were discovered by the New York City Fire Department during a warehouse fire in 1986. In 1987, several children were found playing "doctor" with needles and vials of blood found behind a medical facility in Indiana. Finally, the closure of several beaches, from Maine to the Gulf Coast, due to the presence of washed-up needles, syringes, vials of blood and empty prescription bottles provoked the EPA's institution of the Medical Waste Tracking Act of 1988 (Onel 1989). Fear of improper treatment of medical waste was exacerbated even further by the AIDS epidemic of the 1990's.

Likely because of fear, many hospitals today "over-treat" medical waste. These hospitals generally treat 50% of their waste as biohazardous medical waste (BMW) when only a small portion of a hospital's waste, 10-25%, is actually infectious (WHO 2011, Rutala et al. 1989). Over-treatment of waste causes problems of its own: BMW costs more, mainly due to the insurance costs of its transportation to a off-site treatment facility, and requires more energy to dispose of than municipal solid waste, due to the sterilization process.

This study quantifies the current environmental impacts of a hospital's daily waste disposal in the Phoenix, Arizona area using life cycle assessment (LCA) techniques. Methods and techniques outlined in the International Organization for Standardization (ISO) number 14040 and 14044 are used as the basis of this analysis. The current environmental impacts are then compared with the impacts in the ideal case, when only true BMW is sterilized. In the "business-as-usual" case, it is assumed that 50% of all hospital waste is sterilized, even if it is not biohazardous. For the ideal case, only 16% of the hospital's waste is disposed of as BMW. The ideal case can be enabled through the implementation of a dual waste disposal bin system in operating rooms that allows for proper waste separation in addition to other hospital policy and/or education efforts. The business-as-usual and the ideal cases can be seen in Figure 1. This chart shows the comparison of BMW and non-BMW waste for the two scenarios.

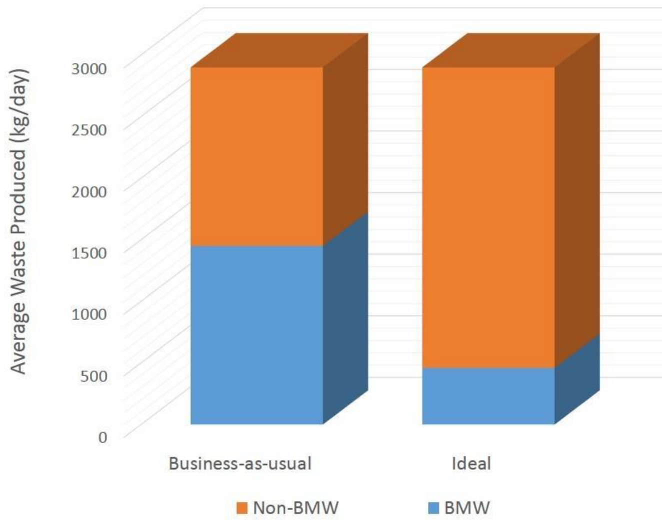

Figure 1: Business-as-Usual and Ideal Scenarios

The two most common practices for treating BMW in the US are autoclave sterilization and incineration. This study only included the autoclave process, because back in 2003, the last incinerator in Arizona was shut down and replaced with the safer method that does not emit toxins into the air (Vogt 2003). An autoclave is a large container that utilizes a steam sterilization technique during which infectious material is subjected to high pressure saturated steam at 121°C for about an hour. For this study, Stericycle is the company responsible for the autoclave process in the boundary diagram. This attributional LCA can be used to demonstrate the importance of BMW reduction, which is possible primarily by diverting more non-hazardous waste out of the BMW stream, as well as other BMW reduction strategies.

Methodology

Boundary Definition

The system boundary for this LCA, shown in Figure 2, tracks biohazardous medical waste (BMW) from the back door of a Phoenix-area hospital as it is transported to Stericycle, autoclaved, and transported to a landfill for disposal. A retrospective, end-of-life LCA using this boundary can enable hospital employees and policy makers to understand the environmental impact of placing items in the biohazardous waste bin. The boundary does not include the production processes for the medical equipment and is, therefore, not intended to inform policy makers on their choices pertaining to the types of medical equipment they purchase.

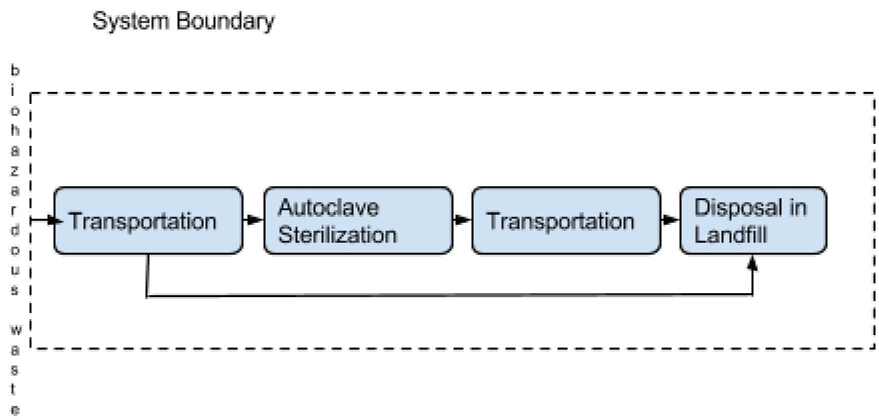

Figure 2: System boundary for end-of-life LCA of biohazardous medical waste

The functional unit -kilograms of BMW produced daily and disposed of to the U.S. Environmental Protection Agency's (EPAs) standard for autoclave- is the unit continually referenced through the system shown above. To be considered safely sterilized and passing the EPA autoclave standard, a Chemical Indicator Strip placed on a flat container in the autoclave must reach the 'steam safe' section, and the maximum temperature reading must be between 120-124 °C (U.S. EPA 2011). Since the Phoenix hospital must adhere to the State of Arizona's regulations, Arizona's definition of BMW is used, which includes in the definition cultures and stocks, human blood and blood products, human pathologic wastes, medical sharps, and research animal wastes (Arizona Administrative Code R18-13-1401(5)).

Three indicators are evaluated through the process of BMW disposal -- global warming potential, fossil fuel use, and human toxicity -- aimed at understanding the three environmental impacts -- climate change, fossil fuel resource depletion, and human health. These indicators are tracked for two scenarios: (1) "business-as-usual" when 50% of hospital waste is autoclaved and (2) "ideal" when 16% of hospital waste is autoclaved. In the ideal case, it is expected that all patient and operating rooms will have two waste bins, one for BMW and another for standard MSW. In order to reach the "ideal" case scenario, it is also expected that the employees within the hospital will be trained to utilize the two bin system and properly separate biohazardous and nonhazardous waste. The functional unit and system boundary remains the same for both scenarios so that a comparison will show the impact of reducing BMW.

Amount and Material Composition of BMW

Fifteen percent of the total waste from healthcare activities is hazardous waste and another 1% is made up of sharps (WHO 2011) which, together, make up BMW as defined by the State of Arizona. The World Health Organization (WHO) estimates North American hospitals generate 7 to 10 kg of waste per bed per day (WHO 1999). Multiplying the average daily waste, 8.5 kg, by 345 patient beds at the Phoenix-area hospital gives an estimated 2,900 kg of waste generated per day, including 460 kg of biohazardous waste per day in an ideal case scenario (Phoenix Children's Hospital n.d.). In the business-as-usual case, 1,450kg of waste would be disposed of as biohazardous waste; this means that by implementing the ideal case scenario, only 460kg of the 2,900 kg is actually BMW. The total amount of waste per day, 2,900 kg, was held constant for both scenarios.

According to Zhao et al. (2008), average solid medical waste consists of the material composition in Table 1. This material mix was compared to data from the WHO on hospitals in Italy, China, and India and, though the data was quite variable, the composition seems reasonable to represent typical medical waste from a hospital. Material composition of biohazardous waste, specifically, was not found in the literature, so it was assumed that the composition of medical waste is representative of BMW.

Table 1 Average composition of the specific medical wastes studied (taken from Zhao et al. 2008)

Category	Waste fraction	Share	Main sources
Biomass	Mix cardboard	10%	Used cardboard
	Wood	5%	Stick
	Textile	30%	Cotton, bandage
Plastic	Mix plastics	45%	Check instruments, IV bag
Rubber	Natural rubber	5%	Single-use gloves, catheter
Sharp	Inert metal	2.5%	Needle, knife, syringe
Glass	Glass	2.5%	Culture, bottle

Transportation Methodology

In order to determine the environmental impacts emitted during transport of medical waste in Arizona, the ecoinvent process 'transport system/road operation, lorry 7.5-16t, EURO5' was used. This assumes that transport in Arizona is comparable to transport in Switzerland and that U.S. emission standards are similar to the EURO5 standard.

There are three transportation phases within the system boundary. One phase transports the contaminated BMW from the hospital, 31 kilometers, to Stericycle to be autoclaved. The waste is reduced in weight by 30% during the autoclave process before the second phase of transport from the Stericycle site to a nearby landfill. The exact landfill used could not be determined, so an average distance to the five nearest landfills, 62 kilometers, was assumed as the second phase transport distance. A third transportation phase moves all of the municipal solid waste, the waste assumed to be non-hazardous, from the hospital to the landfill. The exact landfill used by the hospital could not be determined, so an average distance to the five nearest landfills, 13.2 kilometers, was assumed.

Autoclave Methodology

The autoclave sterilization process was run using a large natural gas boiler system. Because autoclave was not available through ecoinvent to estimate the energy use and emissions for this process, the ecoinvent process 'natural gas/heating system natural gas, burned in boiler modulating, >100kW'was used for this analysis. The LCA data and procedures from Soares et al. (2013) based on a Bench horizontal autoclave, model AB-25 liters that has a 1800W power capacity are used to estimate the average energy generated during the autoclave sterilization process. Based on Soares' data, approximately 0.50 kWh of energy is required per kilogram of waste autoclaved. Since the Phoenix hospital being assessed produces 460 kg of waste per day, in an ideal scenario it would take a daily energy input of 230 kWh to safely sterilize the hospital's waste. For the business-as-usual case, it would require a daily energy input of 725 kWh.

Landfilling Methodology

Carbon dioxide emissions for landfilled waste are calculated using the EPA WARM model and human toxicity and fuel consumption inventories are generated using ecoinvent process 'waste management/sanitary landfill disposal, municipal solid waste, 22.9% water, to sanitary landfill'. This ecoinvent process is based on data from China collected from 1999 to 2000. An impact factor was calculated using the above models and applied to the functional unit. For the business-as-usual scenario, the amount of waste landfilled is reduced during the autoclave process, because about 30% of the weight is lost. This means that more waste is actually being landfilled in the ideal case, since the overall amount of weight reduction during the autoclave process is less. The impacts according to the selected impact categories can be seen in the results section.

The transportation, autoclave, and landfill phases discussed above were analyzed to determine their effect on three environmental impacts -- climate change, fossil fuel resource depletion, and human health -- through conversion to carbon dioxide equivalents, oil equivalents and dichlorobenzene equivalents, respectively. Two scenarios were assessed: business-as-usual and ideal. The scenarios differ in the percentages of the waste sent to Stericycle and the landfill.

Results

Results were generated using ecoinvent output of ReCiPe (E) midpoint analysis and the EPA WARM model. For transportation, the results from ecoinvent were based on all that is required to move a kilogram of material one kilometer of distance. For the autoclave process, results from ecoinvent were based on the generation of one megajoule of energy. For landfilling, the WARM and ecoinvent results were given per kilogram of waste landfilled. Using basic unit conversions, all of the results could be expressed in daily emissions due to the Phoenix hospital's disposal of waste under the two scenarios being examined: business-as-usual (BAU) and ideal. Results for both scenarios are shown in Table 2.

Table 2: Daily emissions related to climate change, human toxicity and fossil fuel depletion due to the disposal of Biohazardous Medical Waste at a Phoenix hospital

	Transport (BAU)	Transport (ideal)	Autoclave (BAU)	Autoclave (ideal)	Landfill (BAU)	Landfill (ideal)	**Total (BAU)**	**Total (ideal)**
GWP_{500} (kg CO2-eq)	18.2	14.4	13.2	4.18	0.51	0.57	**31.9**	**19.2**
FDP (kg oil-eq)	6.86	5.42	5.69	1.80	18.5	20.8	**31.1**	**28.0**
HTPinf (kg 1,4-DCB-eq)	84.1	66.5	7.19	2.28	37,000	41,400	**37,000**	**41,500**

Figure 3, Figure 4, and Figure 5 show which process within the system boundary are generating the greatest global warming, fossil fuel depletion and human toxicity impact potentials.

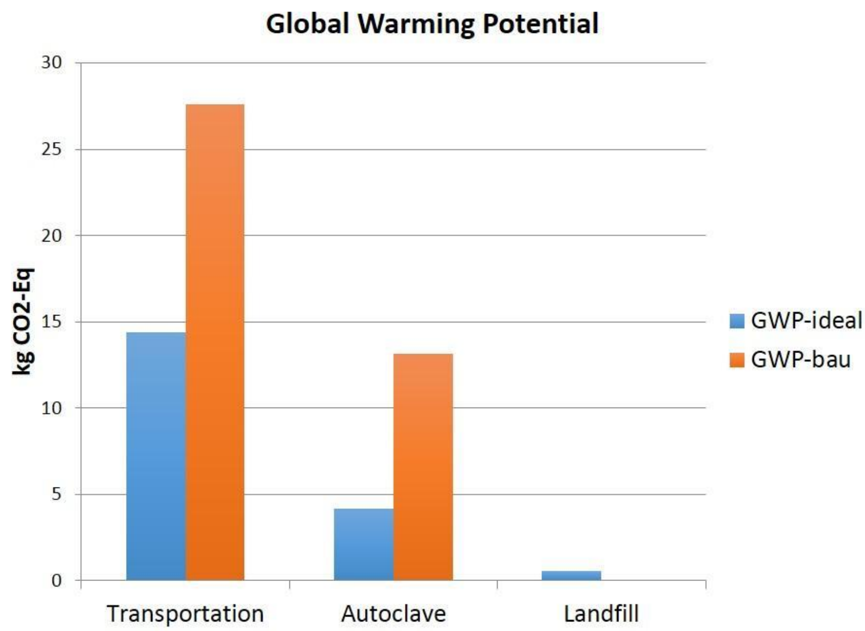

Figure 3: Global Warming Potential for Each Life Cycle Phase

For both the ideal and business-as-usual cases, the transportation phase of the life cycle has the greatest impact on global warming potential (GWP) (Fig. 3; Table 2). For the business-as-usual case, transportation is 57% of the GWP impact, while for the ideal scenario it is 75%. As expected, the total GWP impact for all life cycle stages, as well as overall, is greatest in the business-as-usual case.

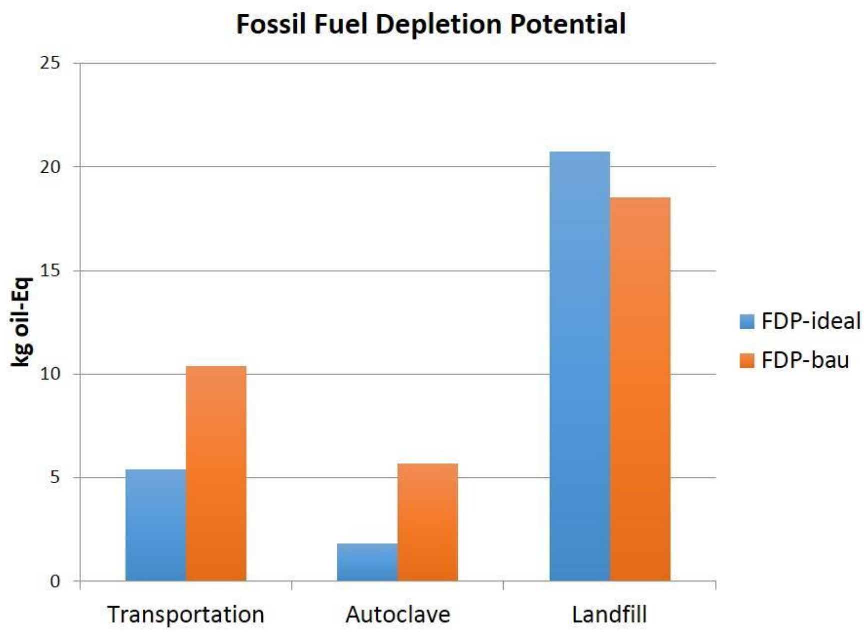

Figure 4: Fossil Fuel Depletion Potential for Each Life Cycle Phase

For the ideal and the business-as usual scenarios, the greatest fossil fuel depletion occurs in the landfill phase of the life cycle. For business-as-usual, the landfill provides 59% of the fossil fuel depletion. In the ideal case, it is 74%. While the fossil fuel depletion is greater for the business-as-usual scenario for the transportation and autoclave phases, in the landfill phase the ideal case is slightly greater.

As seen in Figure 5, the landfilling process accounts for almost all of the emissions of human toxics, and the total weight of waste being landfilled is actually greater in the ideal case than in the business-as-usual case. This is a result of the autoclave process. The autoclave reduces the weight of the waste, and because the business-as-usual case sends more waste through the autoclave than the ideal case, total waste going to the landfill is reduced.

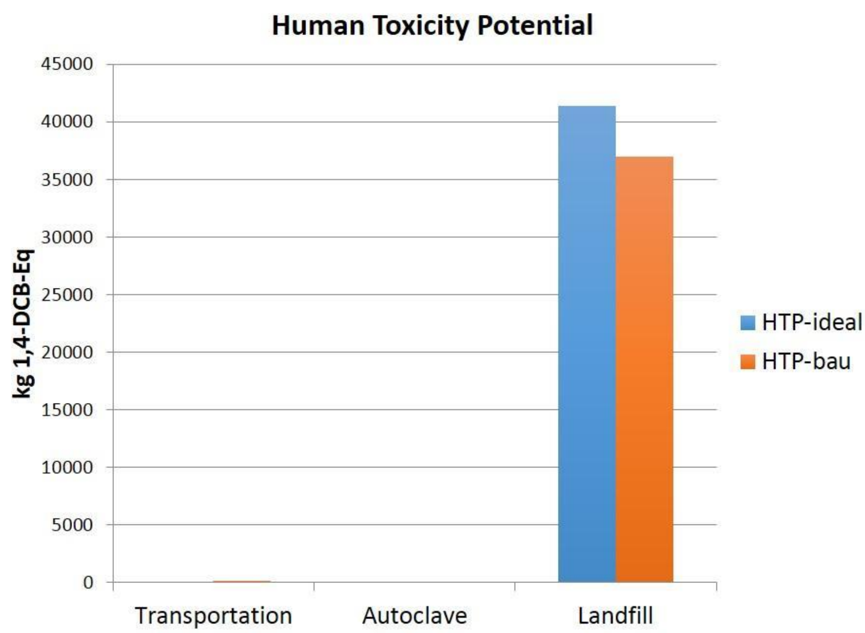

Figure 5: Human Toxicity Potential for Each Life Cycle Phase

A comparison of all emissions for the ideal case versus business-as-usual is shown in Figure 6. The amount of global warming potential and the fossil fuel depletion potential are reduced by 54% and 19% respectively, when moving from business-as-usual to the ideal waste make up. Surprisingly, the human toxicity increases when the hospital changes to the ideal case. The human toxicity impacts during the landfilling process are the impacts of the long period of time that waste is allowed to decompose in the landfill. Many of the products contain carcinogenic material which is released into the environment during decomposition. The unit of human toxicity impacts is kilogram of Dichlorobenzene equivalent. Each carcinogenic material is compared to the exposure risk of Dichlorobenzene and equated on a mass basis. Dichlorobenzene is regulated in drinking water and is assumed by the EPA to be carcinogenic because it has been shown to cause kidney and liver tumors in animals. Carcinogens are the only focused exposure risk considered in the human toxicity impact category, because the unit chosen by the ecoinvent process was equivalent mass of Dichlorobenzene.

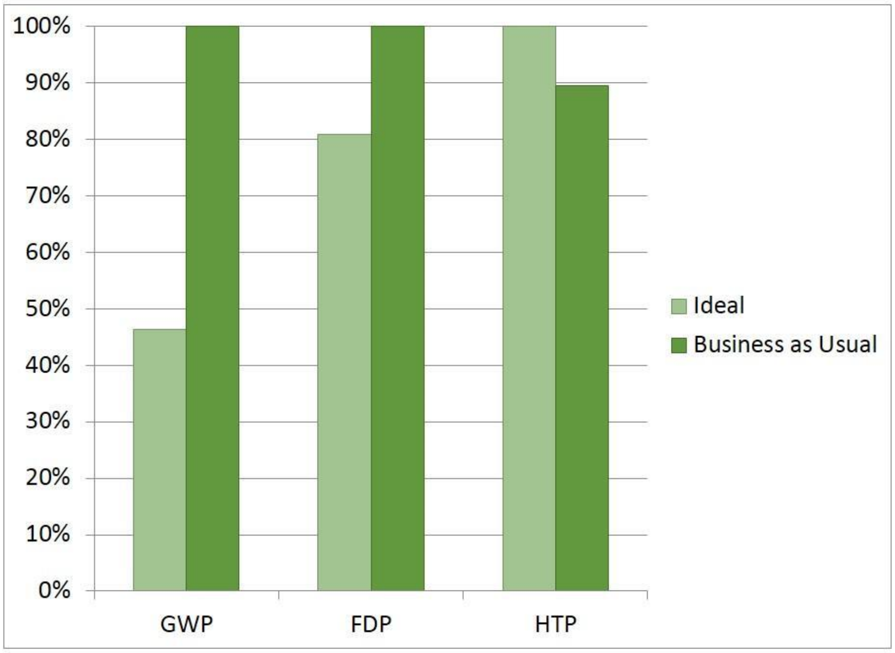

Figure 6: Normalized Impact Categories

Sensitivity and Uncertainty

Sensitivity and uncertainty are major concerns when developing a life cycle assessment. Assumptions, data quality, and temporal and geographic variations in data are all sources of uncertainty within this LCA of medical waste. Also, data may be highly sensitive to some of the assumptions made during the assessment.

Secondary data, mostly from the ecoinvent database, was used in this analysis. While ecoinvent has a fairly robust data gathering technique and provides sources, the low number of data points can introduce uncertainty. For several of the inventories seen above, there was only one data point, a mean, in the ecoinvent database. Also, data from ecoinvent was collected from global, European, and Chinese studies using their respective typical practices and averages. Though this data could have been collected in a sound way, there is uncertainty due to geographical difference. For example, transportation data in ecoinvent were published by the Swiss Centre for LCI and have been validated by the Paul Scherrer Institute, but because the exact truck, fuel, highway structure, etc. are not the same as in Phoenix, geographical uncertainty persists. This data quality can be assessed using a simple scoring method and displayed in a pedigree matrix. The scores are rated 1 through 5 and are based on the criteria derived from a Life

Cycle Assessment class presentation at Arizona State University on the topic of uncertainty (Chester 2014). The criteria and indicator scoring "rubric" can be seen in Figure 7. These indicator scores, shown in the pedigree matrix in Table 3, are used to assess and quantify the uncertainty in the data quality used in the analysis. Three parameters are analyzed in terms of data quality and shown as the pedigree matrix in Table 3. These data inputs and assumptions were chosen because they give a representative look at the other data assumptions not included. Some of the data quality received good scores (the distance to landfill parameter), because they represent data that was sourced from a reputable public agency and the locations of the landfills are not expected to change. Some scores for the Autoclave Process assumptions indicate hotspots for data quality improvement for future work.

Criteria	Indicator Score				
	1	2	3	4	5
Impact on Final Result	Parameter is the top contributor to final result	Parameter is within the top 5 contributors to final result	Parameter is within the top 10 contributors to final result	Parameter is not likely to affect final results significantly	Parameter contribution is unknown
Acquisition Method	Measured data	Calculated data based on measurements	Calculated data partly based on assumptions	Qualified estimate (by industrial expert)	Nonqualified estimate
Independence of Data Supplier	Verified data, information from public or other independent source	Verified information from enterprise with interest in the study	Independent source, but based on nonverified information from industry	Nonverified information from industry	Nonverified information from the enterprise interested in the study
Representation	Representative data from sufficient sample of sites over and adequate period to even out normal fluctuations	Representative data from smaller number of sites but for adequate periods	Representative data from adequate number of sites, but from shorter periods	Data from adequate number of sites, but shorter periods	Representativeness unknown or incomplete data from smaller number of sites and/or from shorter periods
Temporal Correlation	Less than three years of difference to year of study	Less than five years of difference	Less than 10 years of difference	Less than 20 years of difference	Age unknown or more than 20 years of difference
Geographical Correlation	Data from area under study	Average data from larger area in which the area of study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown area or area with very different production conditions
Technological Correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study, but from different enterprises	Data from processes and materials under study, but from different technology	Data on related processes or materials, but same technology	Data on related processes or materials, but different technology
Range of Variation	Estimate is a fixed and deterministic number	Estimate is likely to vary within a 5% range	Estimate is likely to vary within a 10% range	Estimate is likely to vary more than 10%	Estimate is likely to vary under unknown ranges

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Figure 7: Data Quality Scoring for Pedigree Matrix (Chester 2014)

Table 3: Data Quality Assessment using a Pedigree Matrix

Criteria	Parameter Score		
	Distance to Landfill	**Landfill Recovery**	**Autoclave Process**
Impact on Final Result	4	1	2
Acquisition Method	3	3	3
Independence of Data Supplier	1	1	3
Representation	1	1	5
Temporal Correlation	1	2	3
Geographical Correlation	1	3	3
Technological Correlation	1	1	4
Range of Variation	1	3	5

For the autoclave process, secondary data was used to determine the energy use and emissions of the BMW sterilization. Due to the lack of research that has been published on autoclaves, as opposed to other sterilization systems, the data for this portion of the LCA is based on one paper, Soares et al. (2013,) and the ecoinvent process 'natural gas/heating system natural gas, burned in boiler modulating, >100 kW.' The ecoinvent process was utilized under the assumption that the autoclave is run on a large boiler system and that there would not be a significant loss of energy between the boiler running the autoclave and the actual sterilization process. Using the ecoinvent process for determining the emissions of the autoclave does leave out the potential impacts, in particular human health toxicity, that can occur due to the waste water from the sterilization process. There is a lack of published research on the impacts of autoclave waste water, so this portion of the process was left out of the system boundaries under the assumption that it would not be too large of an impact; however, this is a large uncertainty. The human toxicity impact results of the autoclave life cycle phase are very low compared to the landfill life cycle phase. Including the wastewater in the system boundary would probably increase the human toxicity impacts of the autoclave life cycle phase. Additionally, information from Stericycle on the specific autoclave used in Phoenix (different Stericycle locations utilize different autoclave sizes and can, therefore, have different energy requirements) was unable to be obtained.

For the landfilling process, the EPA WARM tool was used to estimate greenhouse gas emission from the disposal of medical waste. Several assumptions are made when implementing this tool that introduces another source of uncertainty to the study. Some of the materials that make up BMW are not explicitly described by the WARM model, so some assumptions and generalizations are made. For example, instead of determining the greenhouse gas emissions from textiles, composed of cotton and bandage, greenhouse gas emissions are estimated using the WARM estimations for carpet in a landfill. While these materials may be similar, the differences in their decomposition processes may introduce uncertainty in the analysis. The material makeup of medical waste seen in Table 1 is the makeup of medical waste and not necessarily the makeup of biohazardous medical waste but was used due to the lack of specific data on biohazardous medical waste material makeup. The WARM model also requires an input of whether the landfill uses energy recovery from biogas production or not. The national average was used for energy recovery at the landfill and may not be specific to Arizona. A pedigree matrix was used to better understand the major uncertainties in this project.

Fuel consumption and emissions from the hospital to Stericycle in a box-truck were verified using the average miles per gallon for a diesel truck (7.2) (Stericycle, Inc. 2012), the distance between the locations (31 km), the average garbage truck load (12 tonnes) (SCDHEC), and the "Greenhouse Gas Emissions from a Typical Passenger Vehicle" (EPA 2011) to help understand the magnitude of the geographical uncertainty in the transportation data. The verification calculation estimated 8.5 kg CO_2 emissions attributable to the daily transport of 1450 kg of waste from the hospital to Stericycle in business-as-usual case, while ecoinvent estimates 9.7 kg CO_2-Eq for the same inputs. It is expected that the verification method be slightly lower than the ecoinvent method due to the calculated units. The hand calculations resulted in kg of CO_2 rather than the CO_2-Eq from ecoinvent. This means that other compounds that lead to global warming were factored into the ecoinvent number, but not considered in the hand calculations. The numbers are relatively close to one another, which provide confidence in the transportation data used from the ecoinvent database.

Studies were done to understand the sensitivity of the data to the amount of waste generated per hospital bed, the number of beds in use, the distance to the landfill, and the amount of energy recovery at the landfill. It was determined that the results remain the same and policy recommendation do not change based on the amount of waste generated per hospital bed within the given range of 7 to 10 kg, the number of beds in use for the range from 25% to 100%, or for the distance to the landfill when considering the closest versus the fifth closest locations. The climate change result was highly sensitive to landfill gas recovery. However, global warming potential is most significant in the transportation and autoclave phases; landfill has very little relative contribution to climate change.

Interpretation

The results indicate that, given the proposed assumptions, a hospital that moves from its business-as-usual over-treatment of BMW to an ideal state of sterilizing pure BMW will reduce its daily global warming potential by 13 kg CO_2-Eq each day. This equates to a 4700 kg CO_2-Eq reduction each year. According to the Climate Neutral Group, this is the equivalent of burning 1500 liters of diesel, using 1,400 kg of office paper, or breathing for 2,300 days. Though landfill CO_2-Eq emissions are highly sensitive to energy recovery, the landfills contribution to CO2-Eq emissions relative to the transportation and autoclave processes in the system boundary are very small. The main source of uncertainty in climate change impacts in this study is related to the choice in autoclave process. In future work, primary data from an autoclave should be collected and analyzed rather than reliance on the related boiler system emissions.

Making the switch to the ideal sterilization of BMW has less of an effect on fossil fuel resource depletion and human toxicity. The study found that a change to the ideal case would reduce fossil fuel depletion impacts by 19% and increase human toxicity impacts by 10%. The uncertainty due to the autoclave process chosen could significantly impact the fossil fuel resource results and the unknown chemistry of the waste water produced by the autoclave could significantly impact the human toxicity results. For future work, it is again recommended to monitor a specific autoclave for data, as quality data on autoclaves does not exist in the traditionally used databases. Also, the waste water from the autoclave should be analyzed for contents of human toxics and other impactful pollutants.

Discussion

This study was completed as a reference point for hospitals to gauge the environmental impact of mandating a comprehensive BMW reduction program. Though a Phoenix-area hospital was used as a baseline for initial data, this information can be useful to any hospital in the United States (US) seeking to understand the environmental implications of BMW when sterilized using an autoclave. There are considerable economic benefits to reducing BMW, because hospitals are charged per pound for waste hauled. The economic benefits can produce significant savings because hospitals are charged, on average, $0.28 per pound of BMW versus $0.05 per pound for solid waste ("Frequently Asked Questions"). The savings vary from hospital to hospital depending on the initial waste baseline; however, according to a 2012 study, if all hospitals in the US adopted BMW reduction strategies the national health care system could save $5.4 billion over five years (Moyle et al 2014).

A typical BMW waste reduction program would involve a waste assessment of every department in the hospital to understand where and how much BMW is generated in order to introduce the appropriate waste segregation system. Once the waste assessment is completed, new waste containers need to be purchased in order to have two options for waste disposal: one for BMW (usually a red container) the other for solid waste that is not soaked or saturated with biohazardous material. Before the new waste program is introduced, all staff in the hospital needs to be trained on the new program to ensure only those items that fit the definition of BMW are discarded in a red container. Education is vital to ensure the hospital is in compliance and is able to obtain the goal of 16% BMW for the entire waste stream.

As the study shows, the highest impact on human toxicity was the landfill, which is why it is in the hospital's best interest to consider waste in their promise to "do no harm." When it comes to hospital waste, it is impossible to completely eliminate it; however, hospitals can do less harm by decreasing what is autoclaved and what is sent to the landfill. The "ideal" case for BMW outlined above only examined the environmental implications of a BMW reduction and did not take into account the environmental implications of recycling and reducing waste. Hospitals will generally set up recycling when rolling out a BMW waste reduction program, so they can educate their staff on both programs at once. If recycling was implemented, about 30% of the overall waste from the hospital would not go to a landfill ("Waste"); thus, the environmental impacts mentioned above would be further reduced. Recycling in hospitals would allow recycling of the typical materials, such as paper, plastics, and metal, unless it is contaminated with BMW. For example, in the operating room (OR), 19% of the OR waste stream is a recyclable polypropylene plastic, called medical blue wrap, that keeps surgical equipment sterile during transportation to the OR (Moyle et al). Apart from recycling, there are many opportunities for reuse in the hospital. For example, medical blue wrap could be phased out by utilizing reusable sterile cases for the OR equipment. Additionally, other one-use items can be replaced with reusable options, such as reusable gel positioners with washable removable covers that hold patient's limbs in place during surgery, versus the one-use foam positioners. In the operating room, further steps can be used to reduce BMW such as reprocessing medical devices and launching a reusable sharps container program.

Conclusion

This life cycle assessment brought insight into how BMW is handled, treated, and disposed of in Arizona. The analysis used the methods and procedures outlined in the ISO standards 14040 and 14044. These standards are commonly used among the life cycle assessment community. The handling of waste at the hospital can be greatly improved to reduce the environmental impacts of the waste. For this study, only global warming potential, fossil fuel depletion potential, and human toxicity potential were used as impact categories but the study could be greatly expanded by including more impact categories. The overall interpretation of this analysis is exactly what the team hypothesized, that by reducing the amount of waste treated as BMW at a hospital it is possible to reduce the environmental impacts of that waste disposal. Future work remains to further detail the impacts of BMW on human health and the environment and to persuade hospitals to reduce their BMW production.

References

Arizona Administrative Code R18-13-1401(5)

Ecoinvent

EPA WARM model

Chester, M. (2014) "Uncertainty." Lecture Presentation. *Life Cycle Assessment for Civil Systems, Arizona State University.* 3 Apr.

"Frequently Asked Questions."(2014). *Practice Greenhealth.* Retrieved from https://practicegreenhealth.org/node/16157

Klangsin, P., & Harding, A. K. (1998). Medical waste treatment and disposal methods used by hospitals in Oregon, Washington, and Idaho. *Journal of the Air & Waste Management Association*, 48(6), 516-526.

Moyle, J. K., and DeLoach, C. (2014) "The Business Case for Sustainability in Surgery." *Practice Greenhealth*. Retrieved from https://practicegreenhealth.org/about/press/news/business-case-sustainability-surgery

Onel, S. (1989) The Medical Waste Tracking Act of 1988: Will it protect our beaches? *Virginia Environmental Law Journal*, 9, 225-248.

Phoenix Children's Hospital. (n.d.) Side-by-side Comparison of Phoenix. Retrieved from http://www.phoenixchildrens.org/sites/default/files/about/spotlight-stories/strategic-alliance/SJH-to-PCH-comparison.pdf

Rutala, W.A., Odette, R.L, and Samso, G.P. (1989). Management of Infectious Waste by US Hospitals. *JAMA*, 262(12), 1635-1640.

Soares, S. R., Finotti, A. R., Prudêncio da Silva, V., & Alvarenga, R. A. (2013). Applications of life cycle assessment and cost analysis in health care waste management. *Waste Management*, *33*(1), 175-183.

South Carolina Department of Health and Environmental Control (SCDHEC). *How Landfills Work.* Retrieved from http://www.scdhec.gov/environment/lwm/recycle/pubs/landfill_102.pdf

Stericycle, Inc. (2012). 2013 Green Tier Annual Report.

U.S. EPA Office of Transportation and Air Quality. (2011). Greenhouse Gas Emissions from a Typical Passenger Vehicle. U.S. EPA. Dec.

U.S. EPA SOP QC-13-05. (2011). *Standard Operating Procedure for Performance Verification of Autoclaves*. Retrieved from http://www.epa.gov/pesticides/methods/atmpmethods/QC-13-05.pdf.

Vogt, H. (2003) "We Shouldn't Have to Be a Dumping Ground": The Gila River Alliance Shuts down a Stericycle Medical Waste Incinerator in Arizona. *Dollars and Sense*. 1 Mar.

"Waste." (n.d.) *Practice Greenhealth*. Retrieved from https://practicegreenhealth.org/topics/waste

World Health Organization. (1999). Chapter 2: Definition and Characterization of Healthcare Waste. *Safe Management of Waste from Health-care Activities.* Retrieved from http://www.who.int/water_sanitation_health/medicalwaste/002to019.pdf

World Health Organization. (2011). Waste from health care activities-fact sheet. Retrieved from http://www.who.int/mediacentre/factsheets/fs253/en/

Zhao, W., van der Voet, E., Huppes, G., and Zhang, Y. (2009). Comparative life cycle assessments of incineration and non-incineration treatments for medical waste. *International Journal of Life Cycle Assessment*, 14, 114-121.