A peer-reviewed version of this preprint was published in PeerJ on 22 February 2019.

View the peer-reviewed version (peerj.com/articles/6204), which is the preferred citable publication unless you specifically need to cite this preprint.

McPherson B, Sharip M, Grimmond T. 2019. The impact on life cycle carbon footprint of converting from disposable to reusable sharps containers in a large US hospital geographically distant from manufacturing and processing facilities. PeerJ 7:e6204
https://doi.org/10.7717/peerj.6204

The impact on global warming potential of converting from disposable to reusable sharps containers in a large US hospital geographically distant from manufacturing and processing facilities

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Background. Sustainable purchasing can reduce greenhouse gas (GHG) emissions at healthcare facilities (HCF). A previous study found that converting from disposable to reusable sharps containers (DSC, RSC) reduced sharps waste stream GHG by 84% but, in finding transport distances impacted significantly on GHG outcomes, recommended further studies where transport distances are large. This case-study examines the impact on GHG of nation-wide transport distances when a large US health system converted from DSC to RSC.

Methods. The study examined the facility-wide use of DSC and RSC at Loma Linda University Health (LLUH), an 1100-bed US hospital system where: the source of polymer was distant from the RSC manufacturing plant; both manufacturing plants were over 3,000 km from the HCF; and the RSC processing plant was considerably further from the HCF than was the DSC disposal plant. Using a “cradle to grave” life cycle assessment (LCA) tool we calculated annual GHG emissions (CO_2, CH_4, N_2O) in metric tonnes of carbon dioxide equivalents ($MTCO_2eq$) to assess the impact on global warming potential (GWP) of each container system. Primary energy input data was used wherever possible and region-specific impact conversions used to calculate GWP of each activity over a 12-month period. Unit process GHG were collated into Manufacture, Transport, Washing, and Treatment & disposal. Emission totals were workload-normalized and analysed using CHI^2 test with $P \leq 0.05$ and rate ratios at 95% CL.

Results. Using RSC, LLUH reduced its annual GWP by 162.4 MTCO2eq (-65.3%; $p < 0.001$; RR 2.27-3.71), and annually eliminated 50.2 tonnes of plastic DSC and 8.1 tonnes of cardboard from the sharps waste stream. Of the plastic eliminated, 31.8 tonnes were diverted from landfill and 18.4 from incineration.

Discussion. Unlike GHG reduction strategies dependent on changes in staff behaviour (waste segregation, recycling, turning off lights, car-pooling, etc), purchasing strategies can enable immediate, sustainable and institution-wide GHG reductions to be achieved. Medical waste containers contribute significantly to the supply chain carbon footprint and, although non-sharp medical waste volumes have decreased significantly with avid segregation, sharps wastes have increased, and can account for up to half of total medical waste mass. Thus, converting from DSC to RSC can assist reduce the GWP footprint of the medical waste stream. This study confirmed that large transport distances between polymer manufacturer and container manufacturer; container manufacturer and user; and/or between user and processing facilities, can significantly impact the GWP of sharps containment systems. However, even with large transport distances, we found that a large university health system significantly reduced the

GWP of their sharps waste stream by converting from DSC to RSC.

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Abstract

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HCF; and the RSC processing plant was considerably further from the HCF than was the DSC disposal plant. Using a "cradle to grave" life cycle assessment (LCA) tool we calculated annual GHG emissions (CO_2, CH_4, N_2O) in metric tonnes of carbon dioxide equivalents ($MTCO_2eq$) to assess the impact on global warming potential (GWP) of each container system. Primary energy input data was used wherever possible and region-specific impact conversions used to calculate GWP of each activity over a 12-month period. Unit process GHG were collated into Manufacture, Transport, Washing, and Treatment & disposal. Emission totals were workload-normalized and analysed using CHI^2 test with $P \leq 0.05$ and rate ratios at 95% CL.

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46 transport distances, we found that a large university health system significantly reduced the GWP
47 of their sharps waste stream by converting from DSC to RSC.
48

49 ## INTRODUCTION

50 Healthcare activities account for 5.4% of greenhouse gas (GHG) emissions in the U.K. (NHS,
51 2016; DBEIS, 2017) and 7.6% in U.S. (Chung and Meltzer, 2009) and, in hospitals, more than
52 half of GHG emissions are derived from supply chain goods and services (Chung and Meltzer,
53 2009; NHS, 2016). Many hospitals are adopting green purchasing strategies to reduce their GHG
54 (Chung & Meltzer, 2009; NHS, 2017) – a position supported by the Alliance of Nurses for
55 Health Environments (ANHE, 2017). Replacing disposable products with reusables is such an
56 example (WHO-HCWH 2009, Unger et al., 2016; Karrlson and Ohman, 2005) and, as clinical
57 waste containers are in the top 20 contributors to the supply chain carbon footprint (NHS, 2017),
58 replacing disposable sharps containers (DSC) with reusable sharps containers (RSC) is
59 recommended (PGH, 2013). One life cycle assessment (LCA) found that converting from DSC to
60 RSC achieved a significant reduction in GHG however the hospital was close to where both
61 containers were manufactured and the authors' sensitivity analysis found that transport distances
62 could significantly affect results and recommended that scenarios with large transport distances
63 be investigated (Grimmond and Reiner, 2012). Our case-study compares the annual impact on
64 the global warming potential (GWP) of converting from DSC to RSC at a large U.S. teaching
65 hospital system sited at nation-wide distances from manufacturing plants.
66

67 ## MATERIALS AND METHODS

68 ### Study Overview

69 Using established principles for assessment of the life cycle GHG emissions of goods and
70 services (British Standards Institute, 2011) we utilised a cradle-to-grave life cycle inventory
71 (LCI) and a product-system LCA tool developed specifically for sharps containers and
72 containing some 750 data cells (Grimmond and Reiner, 2012). In a before-after intervention
73 study, we compared the annual GWP of DSC and RSC usage at Loma Linda University Health
74 (LLUH), an 1100 bed university healthcare system with 5 general acute care hospitals and an
75 expansive outpatient clinic system, in Loma Linda, California. Review Board approval by LLUH
76 was waived as no patients, patient data or patient specimens were involved.
77 The LCI itemised all energy-using processes required by each containment system life-cycle as
78 implemented at LLUH. Scope 1, 2 and 3 processes were included in both study years. Unit process
79 GHG were collated into the following life-cycle stages: manufacture (of polymer and containers);
80 transport; washing (RSC); and treatment & disposal. The LCA assessed the GWP of all energy
81 used in these processes (vehicle fuel, gas, electricity, water supply and treatment) and in the
82 manufacture and life cycle of ancillary products (pallets, transport cabinets, cardboard boxes,
83 wash products). The boundary of the system studied, together with inputs, outputs and
84 exclusions, are shown in figure 1.
85 **Data Sources**
86 The following data sources were used in calculating GHG: DSC and RSC resin manufacture
87 (American Chemistry Council, 2010); primary energy input data for DSC and RSC container
88 manufacture (Clarion 2011) and RSC washing (Daniels, 2017); industry-specific data for DSC
89 autoclaving (Daniels, 2012); RSC and DSC transport (DEFRA, 2015); eGRID values for
90 California, Michigan and Illinois power generation (USEPA eGRID 2016); National data for
91 energy inputs for US water supply and treatment (Chini and Stillwell, 2018); Industry data for

manufacture of wash products (Nielsen et al, 2013; Shahmohammadi et al, 2017); Industry data for manufacture of cardboard (NCASI 2017), representative data for manufacture of transporters (USDOE, 2010); Industry-specific data for pallet LCA (DEFRA, 2010): and US national values for incineration of DSC (USEPA WARM, 2018. The same database and values were applied to the relevant unit processes in DSC and RSC systems. Emissions for RSC manufacturing were calculated using a worst-case scenario based on the actual age of the manufacturer's oldest, most frequently used RSC still in service. Although it is theoretically possible for RSC to be recertified for a further period when they reach their certified reuse expiration, for this study their "end-of-life" was taken to be the number of years under the above worst-case scenario. The GHG associated with manufacture of ancillary reusables (transport cabinets and pallets) were calculated on a per trip basis using their expected life span. Data on container size, model number, number used, and total Adjusted Patient Days (APD) (workload indicator) were obtained from LLUH. Total polymer required for manufacture of DSC and RSC was determined by weighing an example of each model of container and multiplying by the number of containers. The conversion-transition period (2 years) was excluded to avoid data overlap. Emission totals for each system's annual use were workload-normalized using APD for the two study years. Results were analyzed using WinPepi v11.65 (WinPepi, 2016). A Yates-corrected $\chi 2$ test was used for the analysis of proportions. Statistical significance was set at $P \leq .05$ and rate ratios calculated using 95% confidence intervals.

System Function, Boundary, Allocation and Classification

The system function provided by the alternative products (DSC, RSC) was the supply of sharps containers for the disposal of sharps waste (biological, chemotherapeutic, pharmaceutical) within LLUH. The functional unit was the supply of each system for a one-year period. Sharps waste is a

115 sub-category of medical waste and comprises items capable of penetrating human skin (e.g. needles,
116 scalpels) which may have the potential to transmit infectious disease or pose a physical or chemical
117 hazard. Because of these hazards, at disposal, all sharps must be safely contained in either DSC or
118 RSC and transported to a treatment facility. With DSC the container is used once and the intact
119 container and contents are subjected to treatment (commonly autoclaving or incineration) prior to
120 landfill. With RSC, the container is automatedly decanted of its contents (which are treated and
121 disposed), and the reusable container is robotically cleaned and decontaminated, and reused a defined
122 number of times. The boundary of the system studied (Figure 1) included the energy required for the
123 following unit processes: raw material extraction; polymer manufacture and transport; container
124 manufacture and transport; transport of full containers to treatment facility; RSC processing-energy
125 (including water supply, water treatment, and wash products); treatment of DSC; transport of treated
126 DSC to landfill; and energy required for electricity generation and supply. Transport fuel processes
127 were calculated from well to wheel. Excluded from the system boundary were treatment of contents
128 (identical in both DSC and RSC), infrastructure and assets, and any inputs and outputs that
129 comprised less than 1% of mass or energy (British Standards Institute, 2011), or were not relevant
130 to GWP.
131 Allocations for emissions were based on a mass basis for polymer production, container production,
132 cardboard cartons, RSC wash products, DSC treatments, and RSC parts recycling. Other allocations
133 for emissions were as follows: transport (truck size and utilization by tonne.km); electricity
134 generation (kWh); water supply and treatment (litre); RSC processing energy (container); RSC
135 transporters (trip); and pallets (trip).
136 Global warming potential was the impact assessment category to which all inventory data was
137 allocated as it is well-known, commonly used and understood by healthcare facilities. A table listing

the raw data for all unit processes in the LCI, including flow, units, emission factors, total GWP, data sources and data-representativeness, accompanies this publication.

RESULTS

DSC were manufactured in Crystal Lakes IL from US-sourced polypropylene polymer, nested in cardboard containers, transported 3,200km to the hospital on wooden pallets, and autoclaved and landfilled without shredding at Vernon CA, 130km from the hospital. The RSC were manufactured in Greenville MI from polymer sourced in Korea, transported 3,500km in reusable, proprietary transporter cabinets to LLUH, and decanted and processed at Fresno CA, 440km from the hospital. A summary of results is presented in the Table.

To service LLUH in the baseline year, 48,460 DSC were manufactured from 50.6 tonnes of polymer and required 8.2 tonnes of corrugated cardboard packaging for transport (see Table). The DSC used did not contain recycled polymer. In California, biological sharps are commonly treated by non-incineration technologies (e.g. autoclave) then landfilled; chemotherapeutic and pharmaceutical sharps must be incinerated (and ash landfilled) – this requires transport interstate as there are no licensed incinerators for such wastes in California. With DSC, this resulted in 31.8 tonnes of plastic DSC being landfilled and 18.8 tonnes of DSC being incinerated (Table 1).

In the RSC year, 2,779 RSC were manufactured from 9.6 tonnes of acrylonitrile butadiene styrene (ABS) polymer, and 0.4 tonnes of cardboard were used for packaging of 412 chemo DSC that were continued to be used (no cardboard is used for RSC packaging). During the RSC study year, approximately 60 RSC required repair with 30 kg parts being recycled (80%) or reused (20%) (nil to landfill), and, with recycling credit, an equivalent of 3.7 RSC were manufactured as replacement containers (2,783 RSC total for year). In the RSC study-year, the manufacture, treatment and

161 disposal of 412 chemotherapy DSC were included. The RSC in this study, certified for 500 uses,
162 were reused an average of 12.0 times/year, giving a theoretical "end-of-life" lifespan of 41.7 years.
163 However a "worst-case" actual lifespan scenario was adopted based on the number of reuses of the
164 most frequently used RSC still in service (each individual RSC is barcoded and uses monitored).
165 Information supplied by the manufacturer stated their most frequently used RSC still in service was
166 19 years old and had been used 360 times, thus giving an expected "worst-case" lifespan of 26.4
167 years. Manufacturing GHG for RSC (calculated by dividing total manufacturing GHG by life
168 expectancy) was 1135 kg CO2eq for a lifespan of 41.7 years (1.3% of total RSC life-cycle GHG) and
169 1795 kgCO2eq for a worst-case lifespan of 26.4 years (2.1% of total RSC life-cycle GHG). The
170 shorter, worst-case lifespan was used in this study. Total GHG emissions and GHG differences
171 between DSC and RSC life cycle stages are shown in Figure 2.
172 Adjusting for the 0.3% APD workload increase in the year of RSC use, sharps management GWP
173 using DSC was 248.6 MTCO2eq, and with RSC use, decreased to 86.20 MTCO2eq, a 162.4
174 MTCO2eq reduction in GWP (65.3%, $p<0.001$, RR 2.27-3.71) (See Table and Figure 2).
175 As the procedure for deposition of sharps into the DSC and RSC was the same, no change in staff-
176 behavior education in the deposition process was necessary.
177

178 **DISCUSSION**

179 **Background and impact of distances**

180 Commercial RSC, first used in US and Australia in 1986, now represent approximately 50%
181 and 75% respectively of the sharps containers used in these countries, and since 1999 have been
182 increasingly used in Canada, UK, Ireland, New Zealand, South Africa and South America.
183 Generally, RSC are reused many times per year and, with rugged construction and effective

184 inspection and repair, may last several decades. Prior to marketing in the U.S., RSC and DSC
185 are required by the U.S. Food and Drug Administration (FDA) to pass identical performance
186 tests and design requirements as stipulated in sharps container standards (FDA, 1993).
187 However, prior to this testing, FDA require RSC:

188 (i) to undergo "lifespan simulation" e.g. be filled & processed for the number of lifespan
189 uses stated by the manufacturer (e.g. 500 times); then,
190 (ii) the same containers be subjected to a transport vibration test, e.g. US Department of
191 Transport Packaging Vibration Standard (USDOT, 2001), and then,
192 (iii) the same containers must pass the tests and performance criteria of a Sharps
193 Container Standard.

194 Likewise, the Canadian sharps container standard does not distinguish between DSC and RSC in
195 its performance test requirements and requires lifespan simulation of RSC prior to testing (CSA,
196 2014).
197 One reason healthcare facilities adopt RSC is for environmental sustainability (PGH, 2013) but
198 quantitative studies confirming this fact are rare (Unger et al 2016, Karrlson & Ohman 2005).
199 Although the same RSC may be reused several hundred times, energy is required for their
200 robotic washing between uses and, being heavier than DSC, their greater weight means more
201 energy is required per unit for transport and manufacture. Ali et al noted that GHG increase
202 considerably when medical waste is transported longer distances (Ali et al, 2017). A previous
203 LCA study found that when container-manufacturing plants and RSC processing plant are close
204 to the healthcare facility (HCF), the conversion to RSC resulted in an 83.5% reduction in GWP,
205 and transport contributed 25.8% to the RSC life-cycle GWP (Grimmond and Reiner 2012). In
206 our study, the HCF was 3,500km from the RSC manufacturing plant, and, more importantly

(because of daily delivery), the RSC processing plant was 440km from the HCF. This resulted in transport GHG accounting for 90.6% of the RSC life-cycle GWP (see Figure 2). However, notwithstanding that these longer distances lessened the GWP differential between DSC and RSC, the conversion to RSC significantly reduced total sharps waste management GWP by 65.3%. The reduced number of container exchanges with RSC (with associated labor reduction) was also noteworthy. The reduction in sharps management GWP with RSC use, while only a small component of the total supply chain emissions at LLUH, has been a positive step in the institution's sustainability strategies. Unlike GHG reduction strategies dependent on changes in staff behaviour (waste segregation, turning off lights, car-pooling, etc), our study confirms that purchasing strategies can enable immediate, sustainable and institution-wide GHG reductions to be achieved.

Impact on GHG over 10 years

The impact of repeated DSC manufacture and one-off RSC manufacture is best illustrated over multiple years. In the LLUH scenario over a 10-year period, 484,600 DSC would need be manufactured compared to 2783 RSC (and 4,120 chemo DSC), and would divert 502 tonnes of plastic from landfill or incineration.

Sensitivity analysis

Manufacturing (of polymer and containers) gave the largest differential between the two systems (See Figure) and is predominantly a function of the energy required for the higher total polymer weight needed to be annually manufactured and molded for DSC. Although more DSC required transportation from the distant manufacturing plant, the daily transport of RSC from the distant

230 processing plant resulted in a similar transportation GWP for both systems over the year (see
231 Figure 2). The sensitivity analysis revealed that variations in RSC lifespan contributed little to
232 the LCA result - reducing RSC lifespan from a theoretical 41.7 years to 26.4 years (used in this
233 study) or 15 years, reduced the DSC:RSC GWP difference by only 0.4%, and 1.3% respectively.
234 Electricity "cleanliness" across US grids (e.g. wind, coal, hydro) is a key variable in comparative
235 GWP analyses (Unger et al., 2016) and the sensitivity analysis in our study showed that differing US
236 electricity sources can alter processing and manufacturing GHG by 82% which, when extrapolated to
237 the total life-cycle GWP, can alter DSC GWP by 23% and RSC GWP by 10%. Optimization of
238 reprocessing of medical products is recommended to lower GHG (Unger et al., 2016) however, in
239 this scenario, RSC reprocessing accounted for only 5.6% of total RSC life-cycle GWP. Our analysis
240 confirmed findings of other studies (Grimmond and Reiner, 2012, Unger et al., 2016), that material
241 reclamation could reduce DSC life-cycle GWP if reclaimed plastic is used to offset virgin polymer
242 use.
243
244 **Other impacts of RSC**
245 The focus of this study was GWP however cost reduction (Grimmond and Reiner, 2012) and
246 sharps injury reduction (Grimmond et al., 2010) have also been associated with RSC use and
247 these factors, together with sustainability and frontline staff satisfaction, were considered prior to
248 adoption of the RSC system by LLUH.
249
250 **Study Limitations and strengths**
251 One limitation of the study was the assumption made in the location of manufacture of polymer
252 for the DSC. To limit the impact of this assumption, the location was conservatively assumed to

be a United States polymer-supplier close to the point of manufacture of the DSC. A second limitation was the use of the UK DEFRA database for transport energy inputs. This was necessary as no relevant United States database using tonne.km was available; however, all databases were applied equally to DSC and RSC systems. Study strengths were in the availability of 12 months of detailed usage data for both systems; the large transport distances compared to previous studies; the use of a conservative RSC lifespan; and the primary and region-specific availability of energy input data for unit processes in both systems.

CONCLUSIONS

- Large RSC transport distances lessen the differential between DSC and RSC GWP, however, RSC still achieved significant GWP reductions over DSC.
- Transport & electricity cleanliness are key factors in GWP of sharps waste management.
- RSC lifespan has minimal effect on LCA comparisons of container-types.
- Purchasing decisions can significantly contribute to HCF GWP-reduction strategies.
- Institution-wide adoption of RSC can reduce GWP with minimal staff behavior-change.

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Table 1 (on next page)

Annual sharps waste stream and GHG: comparison of disposable vs reusable sharps containers at LLUH.

	DSC	RSC
Containers Manufactured	48,460	3195[a]
Containers landfilled annually	35,925[b]	0[c]
Weight plastic landfilled (tonnes)	31.8	0[c]
Weight plastic incinerated (tonnes)	18.8	0.4[d]
Weight cardboard boxes (tonnes)	8.2	0.1[e]
Container exchanges	48,460	33,356[f]
MTCO2eq GWP[g]	248.62	86.19
Adjusted Patient Days (APD)	296,205	297,056
$MTCO_2eq$ GWP per 10,000 APD[h]	8.37	2.90[i] (-65.3%)

GHG, Greenhouse Gas; LLUH, Loma Linda University Health; $MTCO_2eq$, metric tonnes carbon dioxide equivalent; DSC, disposable sharps container; RSC, reusable sharps container; GWP, Global Warming Potential.

[a] 2,779.7 RSC manufactured in year one only, plus 3.7 replacement RSC annually (allowing for reuse and recycling credits), plus 412 chemotherapy/pharmaceutical DSC annually.

[b] 8,245 Chemotherapy/Pharmaceutical DSC were incinerated/yr.

[c] No RSC were landfilled as all parts were either reused or recycled.

[d] Tonnes of chemo/pharma DSC incinerated (412 chemo DSC were used during RSC year)

[e] Chemotherapy DSC packaging.

[f] RSC were larger in fill-line capacity (25.7L vs DSC 18.5L) and exchanged less often than DSC.

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11 [g] Emissions of GHG expressed in terms of global warming potentials, defined as the radiative
12 forcing impact of one mass-based unit (kg) of a given GHG relative to an equivalent unit of
13 carbon dioxide over a given period of time (100 years) (British Standards Institute 2008).
14 [h] 10,000 APD used as workload denominator to normalize base year comparison and facilitate inter-
15 hospital comparisons.
16 [i] 65.3% reduction; $P < 0.001$; Rate Ratio = 2.90; CL(95%) = 2.27-3.71.
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Table 2 (on next page)

System boundary showing inputs, outputs, inclusions and exclusions

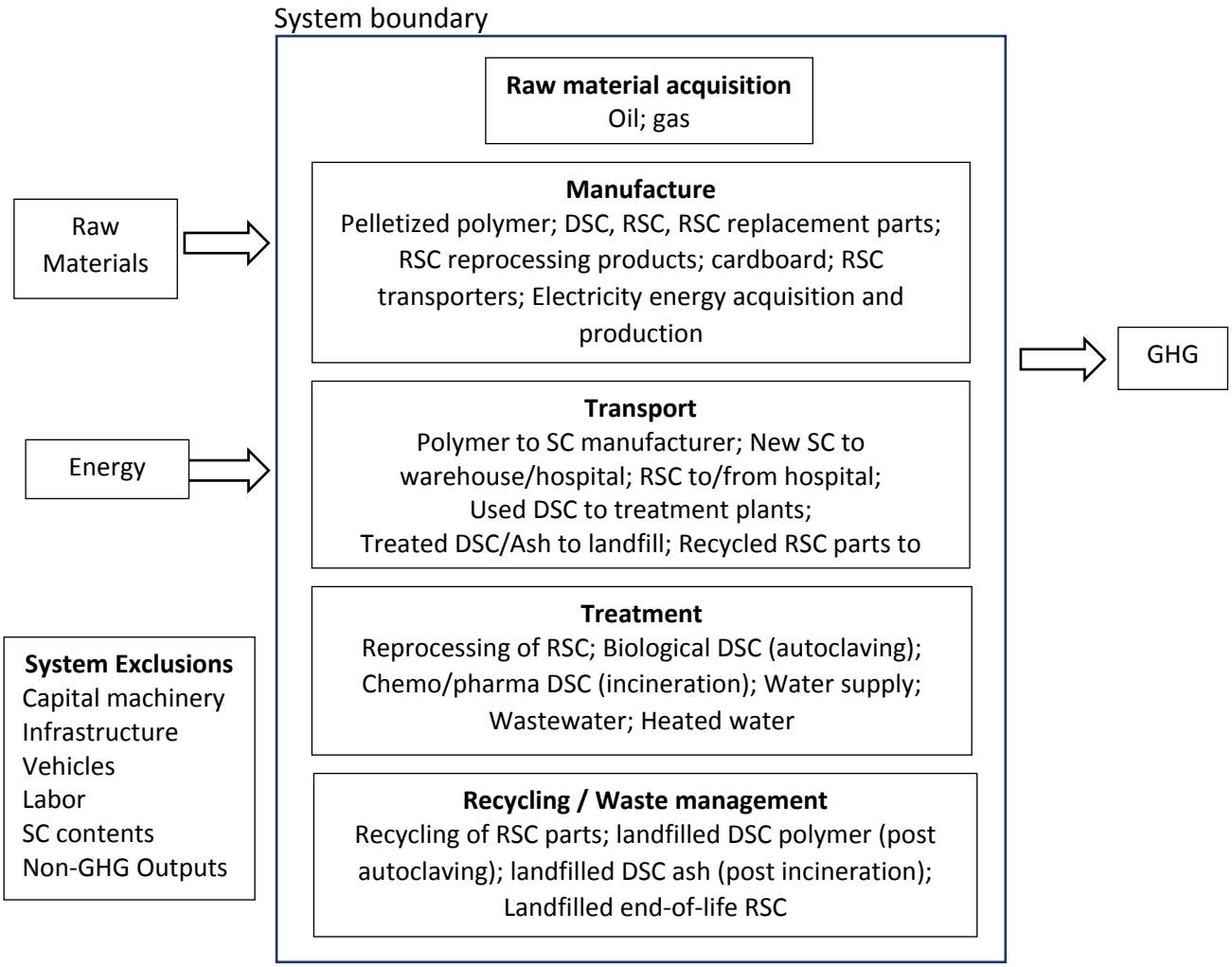
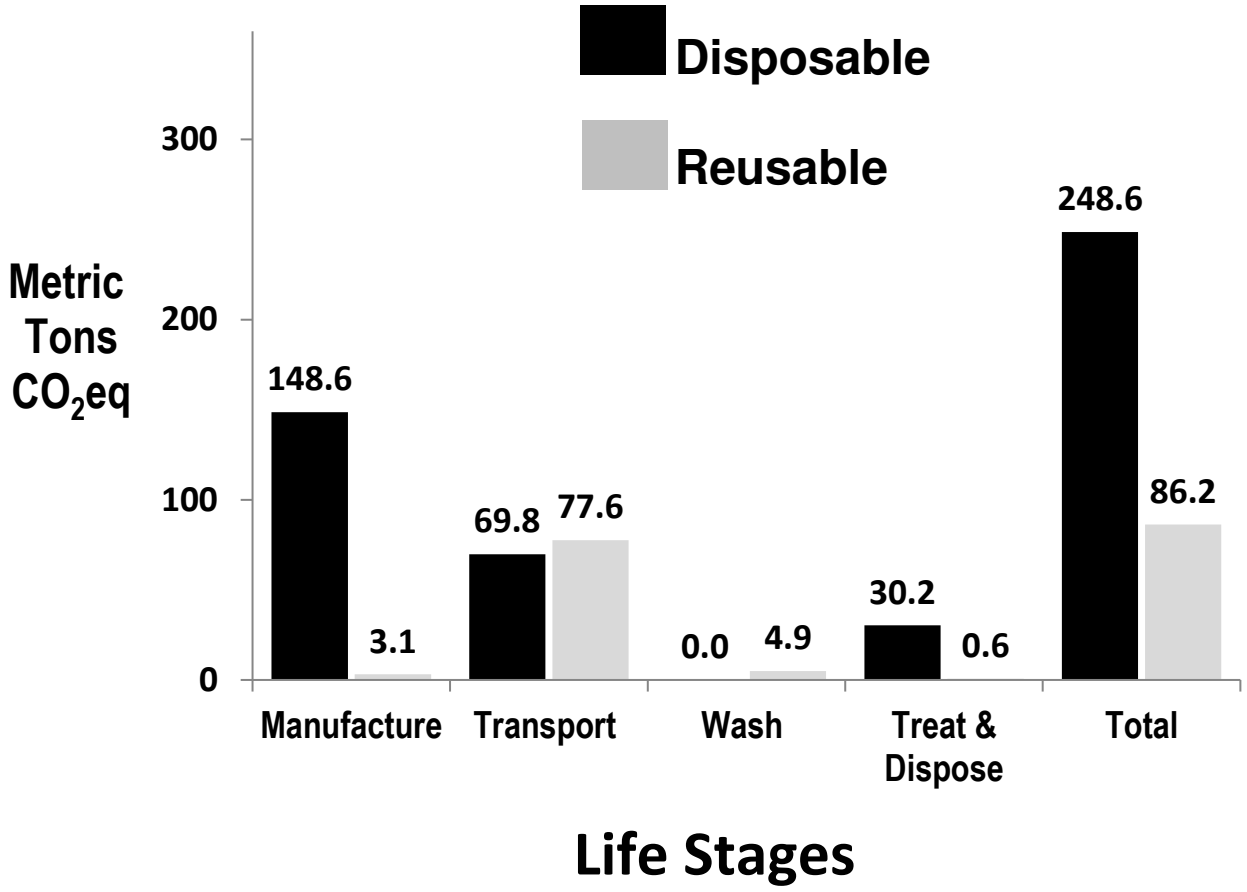


Table 3 (on next page)

Annual greenhouse gas emissions by life stage of disposables and reusable sharps containers at Loma Linda University Hospital, with DSC normalised to Adjusted Patient Days.



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