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## A 24-Hour Waste Audit of the Neuro ICU during the COVID-19 Pandemic and Opportunities for Diversion

Lisette Corbin<sup>a,\*</sup>, Hannah Hoff<sup>a,\*</sup>, Alison Smith<sup>a</sup>, Clint Owens<sup>b</sup>, Kelly Weisinger<sup>c</sup>, Rebecca Philipsborn<sup>d</sup>

<sup>a</sup>Emory University School of Medicine: 100 Woodruff Circle, Atlanta, GA, 30322

<sup>b</sup>New York University Hospital Langone- Brooklyn: 150 55<sup>th</sup> St, Brooklyn, NY, 11220

<sup>c</sup>Office of Sustainability, Emory University and Emory Healthcare: 1599 Clifton Road, Atlanta, GA 30322

<sup>d</sup>Department of Pediatrics, Emory University School of Medicine, Atlanta, GA: 100 Woodruff Circle, Atlanta, GA, 30322

### Abstract

We conducted a series of 24-hour waste audits in a 20-bed pod of a Neurosciences Intensive Care Unit (Neuro ICU) during the COVID-19 pandemic to 1) determine the unit's waste generation practices, 2) calculate associated downstream greenhouse gas emissions, and 3) identify opportunities to reduce landfill waste and emissions. We collected and weighed municipal solid waste, regulated medical waste, and mechanical recycling. We then compared the current, "as-is" practices to an ideal, "should-be" model which adds the alternative waste and reprocessing streams of industrial composting, advanced recycling, and sterilization followed by reuse. We found that the unit produced a total of 97.3 kg of waste over 24 hours, or 4.9 kg of waste per patient per day. 96.8% of this waste is currently landfilled. Emissions generated by processing landfill waste totaled 119.7 metric tons per year of CO<sub>2</sub> equivalents. With the should-be sorting model, 24.7% of total waste produced by the unit could be diverted from landfills. Of this potentially divertible waste, 47.9% could undergo post-consumer industrial composting, 28.0% could undergo mechanical recycling, 22.2% could undergo advanced recycling, and 1.9% could undergo sterilization followed by reuse. Emissions from processing landfill waste in the should-be

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Corresponding author: Lisette Corbin, 100 Woodruff Circle, Atlanta, GA 30322, lisette.corbin@emory.edu, 678-431-8151.

\*Both authors contributed equally to this work

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Lisette Corbin: Conceptualization, Methodology, Investigation, Formal Analysis, Writing- Original Draft, Writing- Review & Editing

Hannah Hoff: Conceptualization, Methodology, Investigation, Formal Analysis, Writing- Original Draft, Writing- Review & Editing

Alison Smith: Conceptualization, Methodology, Investigation, Formal Analysis, Writing- Review & Editing

Clint Owens: Conceptualization, Project Administration, Writing- Review & Editing

Kelly Weisinger: Supervision, Validation, Writing- Review & Editing

Rebecca Philipsborn: Supervision, Validation, Writing- Review & Editing

model totaled 110.6 metric tons per year of CO<sub>2</sub> equivalents, representing a 7.7% decrease. These findings highlight the potential utility of alternate waste streams in this setting as well as the urgent need for complementary upstream waste reduction strategies to meaningfully reduce the Neuro ICU's landfill reliance and greenhouse gas emissions.

## 1.0 Introduction

Climate change has been linked to increased risk of many human diseases, including infectious, respiratory, allergic, psychiatric, and cardiovascular diseases.<sup>1</sup> Healthcare systems perpetuate these health risks through their contribution to climate change, despite the first, do no harm principle inherent in their missions. In the United States, healthcare generates 5.9 million tons of waste per year,<sup>2</sup> or 10.7 kg per bed per day, which is substantially higher than other developed countries.<sup>3</sup> Each year, U.S. healthcare generates 655 million metric tons of carbon dioxide (CO<sub>2</sub>) equivalents, accounting for 8% of national greenhouse gas (GHG) emissions.<sup>1</sup> While only 3% of U.S. healthcare-associated GHG emissions result from waste disposal, this proportion represents millions of tons of CO<sub>2</sub> from healthcare waste each year.<sup>1</sup>

Healthcare-associated waste has ballooned in the COVID-19 pandemic due to increased patient loads, emphasis on infection prevention, and use of disposable items.<sup>4-6</sup> Since the start of the pandemic, 87,000 metric tons of personal protective equipment (PPE) have been procured and shipped worldwide by the United Nations alone, with the expectation that much of that PPE will be discarded.<sup>7</sup> The pandemic also has sharpened focus on supply chain vulnerabilities and healthcare's reliance on single-use products.<sup>8</sup> In addition to these visible impacts on waste production and disposal practices, COVID-19 has resulted in restricted hospital visitation policies and an increase in temporary staff who may be less familiar with waste disposal policies, both of which may influence waste generation.

There are substantial gaps in our understanding of how the COVID-19 pandemic has affected healthcare's waste processing streams. Waste audits of healthcare facilities are an effective means of quantifying the waste produced in the healthcare setting, identifying downstream waste processing streams, and optimizing facility waste management practices. Previous waste audits have surveyed entire hospitals, emergency departments, pharmacies, intensive care units (ICUs), and operating rooms and have identified important opportunities to reduce and divert waste in each setting.<sup>9-14</sup> However, no comprehensive waste audits have yet been undertaken during the COVID-19 pandemic nor in a Neurosciences (Neuro) ICU, despite the unique circumstances of these settings. We sought to fill these gaps in understanding by assessing waste generated in the Neuro ICU with attention to the impact of the COVID-19 pandemic on facility waste.

The objectives of this study were 1) to determine the waste generation practices of a Neuro ICU in a quaternary care hospital during the COVID-19 pandemic, 2) to calculate the associated downstream greenhouse gas emissions, and 3) to identify opportunities to reduce landfill waste and emissions. We quantified and described waste generation in this Neuro ICU over a series of 24-hour periods during the COVID-19 pandemic. We then applied a resorting analysis in which current waste disposal practices were compared to an ideal

model of disposal-- an “as-is” vs. “should-be” framework-- a novel aspect of our study’s design. Finally, we calculated the downstream GHG emissions from processing the unit’s landfill waste and identified opportunities to divert landfill waste and reduce associated GHG emissions.

## 2.0 Materials & Methods

### 2.1 Study Setting

This study was conducted at Emory University Hospital (EUH) in Atlanta, Georgia in a 20-bed pod of the 42-bed Neuro ICU. The Neuro ICU is staffed by specialists trained in neurology and critical care medicine and treats patients referred from across the southeastern United States for conditions such as traumatic brain injury, stroke, subarachnoid hemorrhage, neuromuscular disease, cerebral aneurysm, and neurologic sequelae of COVID-19. The study was conducted with the consent of EUH leadership and safety departments. Institutional Review Board (IRB) exemption was provided by the Emory University IRB board.

### 2.2 Study Design

Our audit captured all waste streams from the Neuro ICU over a series of nonconsecutive 24-hour collection periods from August to October 2021 (Supplemental Table 1). “Waste” was defined as anything disposable leaving the unit, including all items in municipal solid waste (MSW), mechanical recycling, regulated medical waste (RMW), sharps disposal containers, protected health information (PHI) receptacles, and patient meal trays. The study was partially blinded, as only the nurse manager on the unit was aware of study; all other staff generating waste were unaware of the study. Collection was completed by the usual environmental services staff. All waste was collected and weighed as-is, or exactly how it had been discarded by staff and patients.

Waste from the as-is categories was weighed and then sorted into six should-be categories which optimize landfill diversion. The six should-be categories included the three as-is categories (MSW, RMW, and mechanical recycling) and three additional categories: post-consumer industrial composting, advanced recycling, and sterilization followed by reuse. Inclusion criteria for each category was defined by our facility’s vendors (Table 1).

Industrial composting refers to the large-scale processing of organic matter, including food and soiled paper, into nutrient-rich soil.<sup>15</sup> Pre-consumer industrial composting refers to food scraps from the hospital kitchen before reaching consumers while post-consumer industrial composting refers to all organic material that is returned to the kitchen after consumer-contact. This audit examined post-consumer industrial composting.

Advanced recycling refers to the chemical treatment of a variety of clean plastic patient-care items, including those that are too complex to undergo mechanical recycling or are not profitable to mechanical recyclers. These include, but are not limited to, high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS) (plastics #2, #4, #5, #6, respectively). Multiple chemical technologies including purification, decomposition/depolymerization, and thermal conversion are utilized.

While advanced recycling processes require higher volumes of input material to be cost effective than traditional mechanical recycling, they extend the operational life of plastics and avoid degradation of plastic quality that occurs with repeated mechanical recycling.<sup>16</sup>

Sterilization of unopened and unused single-use patient care items followed by reuse is a reprocessing stream. Unopened items from the rooms of patients under isolation precautions are often discarded upon patient discharge due to infection prevention concerns. These items can be decontaminated with vaporized hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) and subsequently returned to the unit's stock. This practice became more common at our facility during the early COVID-19 pandemic to sterilize and reuse personal protective equipment (PPE), such as N-95 respirators, which was in scarce supply. This decontamination can be completed on-site.

### 2.3 Waste Collection & Sorting

Three authors were present for and led all waste sorting and weighing, which was completed with the assistance three volunteers. Any disagreements regarding appropriate waste category were resolved by consensus. All study personnel wore isolation PPE throughout the waste audit. Volunteers and study personnel completed OSHA-compliant bloodborne pathogens training prior to the audit and were vaccinated against hepatitis B and COVID-19.

To protect patient privacy, PHI was weighed as-is without opening or sorting its contents. Sharps containers and RMW containers were unopened to minimize exposure to hazardous and infectious materials. While other waste audits have opened and sorted these streams, our facility did not permit this during the COVID-19 pandemic. Soiled items, such as wet paper, were sorted under the assumption that soiling had occurred after disposal due to co-mingling in the waste receptacle. Un-numbered plastic items were conservatively sorted into MSW as we could not discern their acceptability for mechanical or advanced recycling. Upon completion of the waste sorting, all waste was disposed of in compliance with hospital policy. All waste was weighed using Welch Allyn Tronix Configuration 5002-XX-B scale equipment with a resolution of 0.1 lb.

### 2.4 Data Analysis

Aggregate patient volume data during the 24-hour periods of study and for fiscal year 2021 were collected for normalization. Weights of the as-is and should-be waste were summed, and landfill waste (MSW + RMW) in each scenario was calculated. The GHG emissions generated by processing landfill waste as-is and should-be were calculated using the Mazzetti M+ WasteCare Calculator (San Francisco, CA). The calculations included emissions produced by landfilling for MSW and autoclaving and landfilling for RMW. The waste quantities and landfill associated GHG emissions of the two models were then compared. Data was aggregated using Google Sheets (Mountain View, CA) and analyzed with univariate descriptive statistics using Microsoft Excel (Redmond, WA).

Because we were unable to sort RMW, we could not determine how much RMW should have been categorized as MSW. This uncertainty is relevant when calculating emissions, as processing RMW is more energy intensive than processing MSW because it includes

autoclaving. We therefore performed a sensitivity analysis to model how reallocating varying proportions of RMW to MSW reduces GHG emissions.

### 3.0 Results

Over the 24-hour study periods, the Neuro ICU generated 97.3 kg of waste per day, or 4.9 kg of waste per patient-day (Table 2). MSW represented the largest as-is category, comprising 82.6% of the total weight. RMW was the next largest category, accounting for 14.2% of waste. The smallest category was mechanical recycling, representing 3.2% of all collected waste, 64.5% of which was PHI. In the as-is scenario, 94.2 kg of waste from MSW and RMW was destined for landfills; this represents 96.8% of the total waste generated by the Neuro ICU (Figure 1). Only 3.2% of waste was diverted from landfill, via mechanical recycling.

#### 3.1 Comparison of Waste Stream Utilization in As-is vs. Should-be Models

When sorted into should-be waste categories, MSW remained the largest category but was reduced to 60.3% of total waste. After sorting, RMW remained the second-largest category at 15.0% of total waste. Industrial composting comprised 11.8% of total waste, mechanical recycling 6.9%, advanced recycling 5.5%, and sterilization 0.5%.

The should-be sorting regimen resulted in 72.7 kg of landfill waste, representing 75.3% of total waste (Figure 1). Thus, 24.7% of total waste was divertible from landfills, a 23% reduction in the amount of waste destined for landfills. Of the potentially divertible waste, 47.9% was industrial composting, 28.0% mechanical recycling, 22.2% advanced recycling, and 1.9% sterilization.

#### 3.2 Greenhouse Gas Emissions and Sensitivity Analysis

As-is GHG emissions generated by processing the unit's landfill waste (MSW and RMW) totalled 119.7 metric tons per year (mTPY) of CO<sub>2</sub> equivalents (CO<sub>2</sub>e) (Table 3). With should-be sorting, the landfill-associated emissions decreased to 110.6 mTPY CO<sub>2</sub>e, a 7.7% decrease. The sensitivity analysis models how decreasing the quantity of waste sorted into RMW reduces GHG emissions (Table 4).

### 4.0 Discussion

Over the 24-hour study periods, the 20-bed Neuro ICU generated 97.3 kg of waste per day, 4.9 kg of waste per patient-day and an estimated 35,260 kg of waste per year. Processing this waste generates 119.7 metric TPY of CO<sub>2</sub>e annually, comparable to driving an average passenger vehicle 484,139 km, or 12 times the circumference of Earth.<sup>17</sup> With addition of alternative waste streams, nearly 25% of the Neuro ICU's waste could be diverted from landfills with an associated decrease in landfill-associated emissions of almost 8%. Importantly, even with maximal diversion, the majority of waste would still be destined for landfills. This highlights the urgent need for complementary upstream waste reduction strategies to reduce the Neuro ICU's environmental impact most meaningfully.

#### 4.1 Areas of Opportunity

One key area of opportunity identified was industrial composting, which comprised almost half of the potentially divertible waste. Much of this stream was food waste from returned patient meal trays, one-fifth of which were completely untouched. The Neuro ICU is a unique setting because many patients are unable to eat due to their medical conditions and often do not have meals delivered. Only 12 meal trays were ordered, the equivalent of breakfast, lunch, and dinner for 4 patients, 20% of the patient census (Supplemental Figure 4). Additionally, COVID-19 changes including closed visitor waiting rooms and a one-visitor limit may have reduced the quantity of food and paper food packaging recovered. However, compostable material comprised 11.8% of the total should-be waste which falls within the range reported in previous waste audits: 6.2% in an Emergency Department audit<sup>10</sup> and 17.1–31% in audits of entire hospitals.<sup>18–20</sup> The potential impact of post-consumer composting on diverting food waste from landfills may be even higher in other care settings, and pre-consumer industrial composting's benefits have been demonstrated in hospital kitchens.<sup>21</sup>

Unlike other ICU waste audits,<sup>9,22</sup> our greatest opportunity for waste diversion was not increased sorting into mechanical recycling. Only 3.2% of as-is waste was sorted into mechanical recycling, which increased to only 6.9% of total waste with should-be segregation. This relatively modest increase could be because the hospital's mechanical recycling vendor is limited in the materials they accept: unsoiled paper products, aluminum cans, and polyethylene terephthalate (PET, or plastic #1). Additionally, many potentially acceptable materials were not clean enough to meet the recycler's standards. Although there are abundant MSW containers on the unit, in each patient room and throughout common areas, there were only three mechanical recycling receptacles. Lack of accessibility could make recycling less convenient and contribute to the incorrect sorting of recyclable items as MSW. Additionally, restricted pandemic visitor policies may have decreased the amount of recyclable plastic food packaging disposed of on the unit.

RMW comprised 14.2% and 15.0% of total waste in our as-is and should-be scenarios respectively, falling within the range reported in other hospital settings of 2.8–19.2%.<sup>10–12</sup> However, visual inspection of the RMW bags revealed numerous urine and feces-soaked pads, linens, and bedpans, suggesting a high degree of mis-segregation of MSW into RMW. The Occupational Safety and Health Administration (OSHA) guidelines regarding what constitutes RMW are vague and discretion is left to individual states to define this waste category.<sup>23</sup> Georgia's guidelines define biomedical waste as "blood and blood products, exudates, secretions, suctionings and other body fluids" without delineating fluid quantity or infectious capacity.<sup>24</sup> Much is left to individual interpretation, and as a result, healthcare workers may err on the side of over-utilizing RMW. Our sensitivity analysis models the impact of increasing proportions of the as-is RMW being sorted as MSW, providing valuable insight into how emissions might be reduced. Even if a small percentage of waste currently disposed of as RMW was correctly segregated into MSW, the associated emissions produced by processing decrease substantially. The U.S. lacks evidence-based guidelines outlining the appropriate RMW percent composition in hospital waste; however, Practice Greenhealth, a healthcare sustainability nonprofit, suggests that RMW comprise no more than 10% of total

hospital waste.<sup>25</sup> To reach this goal, the Neuro ICU's RMW would have to decrease by 30%, resulting in a 26.8% decrease in RMW-associated emissions.

Advanced recycling comprised slightly over one fifth of the potentially divertible waste produced. Challenges in implementing this stream would be training staff to discern acceptability as many small plastic items (needle caps, IV parts) are un-numbered and to clean items to meet vendor requirements. However, advanced recycling has the potential to substantially reduce the volume of landfill waste, particularly from procedure-heavy environments as many supply kits contain plastics which can be recycled through chemical processes. Clarity on how advanced recycling programs could interface with the realities and limitations of healthcare waste disposal practices represents an important opportunity for exploration.

The smallest should-be category was the reprocessing stream of sterilization, comprising approximately 2% of potentially divertible waste. There may be greater opportunity for resource recovery in procedural settings where items are often prepared but not used and units with high proportions of patients on isolation precautions such as designated COVID-19 units.

## 4.2 Implications for Practice

Conducting a waste audit allows for elucidation of current waste production practices and identification of the most significant areas of opportunity for waste reduction. Once these areas are identified, tailored diversion strategies can be implemented. While the introduction of alternative waste streams has the potential to reduce landfill waste, successful implementation will require substantial staff-training and buy-in to overcome the inertia of current waste disposal practices.

To further reduce waste, a multipronged approach including upstream waste minimization is necessary. For example, our work in the Neuro ICU helped catalyze the replacement of the unit's single-use isolation gowns with reusable cloth gowns which have an average lifecycle of 50+ uses before disposal.<sup>26</sup> This change has both decreased the unit's waste generation and safeguarded the unit's PPE against COVID-19 related supply chain shortages. Other promising upstream methods include repurposing medical equipment,<sup>27</sup> streamlining surgical kits,<sup>28,29</sup> and optimizing food services' operational procedures,<sup>21</sup> including using reusable dishware and silverware.

## 4.3 Limitations

This study has several limitations. This was an observational, single-center audit conducted over multiple 24-hour time periods during the COVID-19 pandemic in the Neuro ICU, a specific type of care setting which may limit the generalizability of our results. While previous ICU audits have considered the proportion of patients on mechanical ventilation and hemofiltration,<sup>22</sup> we did not access patient records to determine illness severity during waste collection periods. We were unable to open and sort RMW, PHI, and sharps waste to determine correct categorization due to safety and privacy concerns. However, our sensitivity analysis of RMW considered the effects of assumed mis-sorting of RMW. The scale used for all measurements was accurate to 0.1 lb, a potential source of error for smaller quantities of

waste. Meal trays, mechanical recycling, and sharps containers were quantified on different days from other waste. However, patient load and distribution were similar, so the different weekdays are likely equally representative of waste production in the Neuro ICU.

Our GHG calculations were not cradle-to-grave and included only GHG emissions generated by processing landfill waste (MSW and RMW). We recognize that waste comprises a minority of total healthcare GHG emissions, and the majority of ICU emissions derive from electricity and gas utilization.<sup>30</sup> Additionally, annual GHG emissions were calculated based on 24-hour weekday study periods, which may overestimate total annual emissions due to lighter weekend staffing. However, the unit's patient census is stable at 95% or greater bed-occupancy year-round. This study calculated GHG emissions using Mazzetti's M+ WasteCare Calculator tool, which has embedded assumptions about landfilling and autoclaving. Other models may estimate emissions differently.

## 5.0 Conclusion

Almost one-quarter of waste from the Neuro ICU could be diverted from landfills through the implementation of alternative waste and reprocessing streams including industrial composting, mechanical and advanced recycling, and sterilization. This would result in a 7.7% decrease in GHG emissions produced by processing landfill waste. Upstream waste reduction is an urgent and essential strategy to complement waste diversion to reduce the environmental impact of the Neuro ICU and to fulfill healthcare's mission to do no harm.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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## References

1. Karliner J, Slotterback S, Boyd R, Ashby B, Steele K. Health Care's Climate Footprint: How the Health Sector Contributes to the Global Climate Crisis and Opportunities for Action. *Health Care Without Harm* 2019 September.
2. Voudrias EA. Healthcare waste management from the point of view of circular economy. *Waste Manag* 2018;75:1–2. [PubMed: 29699811]
3. Windfeld ES, Brooks MS. Medical waste management - A review. *J Environ Manage* 2015;163:98–108. [PubMed: 26301686]
4. Chowdhury T, Chowdhury H, Rahman MS, Hossain N, Ahmed A, Sait SM. Estimation of the healthcare waste generation during COVID-19 pandemic in Bangladesh. *Sci Total Environ* 2021;811:152295. [PubMed: 34896490]



5. Fadaei A Study of solid waste (municipal and medical) management during the COVID-19 pandemic: a review study. *Rev Environ Health* 2021.
6. McGain F, Muret J, Lawson C, Sherman JD. Effects of the COVID-19 pandemic on environmental sustainability in anaesthesia. Response to *Br J Anaesth* 2021;126:e118–e119. *Br J Anaesth* 2021;126:e119–e22.
7. Montgomery M, Hayter A, Klu J, Pieper U. Global analysis of healthcare waste in the context of COVID-19: status, impacts and recommendations2022.
8. Hu X, Davies R, Morrissey K, et al. Single-use plastic and COVID-19 in the NHS: Barriers and opportunities. *J Public Health Res* 2021.
9. McGain F, Story D, Hendel S. An audit of intensive care unit recyclable waste. *Anaesthesia* 2009;64:1299–302. [PubMed: 19804429]
10. Hsu S, Thiel CL, Mello MJ, Slutzman JE. Dumpster Diving in the Emergency Department. *West J Emerg Med* 2020;21:1211–7. [PubMed: 32970577]
11. R Z, D J, J G, W S. An Audit of All Waste Leaving the Operating Room: Can the Surgical Suite Be More Environmentally Sustainable? *World Medical & Health Policy* 2021;13:126–36.
12. Stall NM, Kagoma YK, Bondy JN, Naudie D. Surgical waste audit of 5 total knee arthroplasties. *Can J Surg* 2013;56:97–102. [PubMed: 23351497]
13. Tisdall J, Edmonds M, McKenzie A, Snoswell CL. Pharmacy-led ward-based education reduces pharmaceutical waste and saves money. *Int J Pharm Pract* 2019;27:393–5. [PubMed: 30828900]
14. Studnicki J The management of hospital medical waste. How to increase efficiency through a medical waste audit. *Hosp Top* 1992;70:11–20.
15. What is Industrial Composting? University of Colorado Boulder, 2020. (Accessed 17 January, 2022, at <https://www.colorado.edu/center/2020/12/10/what-industrial-composting>.)
16. Ragaert K, Delva L, Van Geem K. Mechanical and chemical recycling of solid plastic waste. *Waste Manag* 2017;69:24–58. [PubMed: 28823699]
17. Greenhouse Gas Equivalencies Calculator. United States Environmental Protection Agency, 2021. (Accessed January 17, 2022, at <https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator>.)
18. Ferreira AP, Veiga MM. Hospital waste operational procedures: a case study in Brazil. *Waste Manag Res* 2003;21:377–82. [PubMed: 14531523]
19. Altin S, Altin A, Elevli B, Cerit O. Determination of Hospital Waste Composition and Disposal Methods: a Case Study. *Polish Journal of Environmental Studies* 2003;12:251–5.
20. Dehghani MH, A K, C F. Assessment of medical waste management in educational hospitals of Tehran University Medical Sciences. *Iranian Journal of Environmental Health Science and Engineering* 2008;5:131–6.
21. Thiel CL, Park S, Musicus AA, et al. Waste generation and carbon emissions of a hospital kitchen in the US: Potential for waste diversion and carbon reductions. *PLoS One* 2021;16:e0247616. [PubMed: 33730046]
22. Kubicki MA, McGain F, O’Shea CJ, Bates S. Auditing an intensive care unit recycling program. *Crit Care Resusc* 2015;17:135–40. [PubMed: 26017132]
23. Standard Number 1910.1030 - Bloodborne pathogens. 19101030(b): Occupational Safety and Health Administration; 2019.
24. Biomedical Waste. Rule 391-3-4-15: Georgia Department of Natural Resources; 2022.
25. Sheehan K High Success Through Low RMW Rates. *Greening the OR Symposium*. Reston, Virginia: Practice Greenhealth; 2015.
26. Kilinc FS. A Review of Isolation Gowns in Healthcare: Fabric and Gown Properties. *J Eng Fiber Fabr* 2015;10:180–90. [PubMed: 26989351]
27. Kwakye G, Pronovost PJ, Makary MA. Commentary: a call to go green in health care by reprocessing medical equipment. *Acad Med* 2010;85:398–400. [PubMed: 20182109]
28. Zygourakis CC, Yoon S, Valencia V, et al. Operating room waste: disposable supply utilization in neurosurgical procedures. *J Neurosurg* 2017;126:620–5. [PubMed: 27153160]
29. Farrelly JS, Clemons C, Witkins S, et al. Surgical tray optimization as a simple means to decrease perioperative costs. *J Surg Res* 2017;220:320–6. [PubMed: 29180198]

30. McGain F, Burnham JP, Lau R, Aye L, Kollef MH, McAlister S. The carbon footprint of treating patients with septic shock in the intensive care unit. *Crit Care Resusc* 2018;20:304–12. [PubMed: 30482138]

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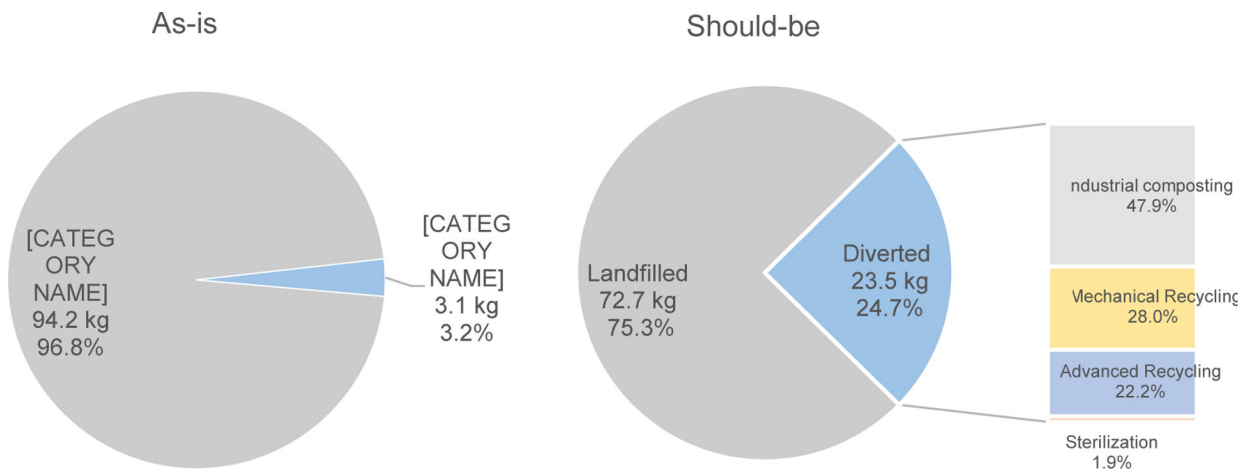
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### Highlights

- This waste audit was the first conducted in a Neuro ICU during COVID-19 pandemic
- Our analysis employs a novel “as-is” versus “should-be” waste disposal framework
- The Neuro ICU generates 35,260 kg of waste and 120 metric tons CO<sub>2</sub>e annually
- Industrial composting offers greatest opportunity to increase landfill diversion
- 75% of waste is landfilled with maximal diversion stressing waste reduction need



**Figure 1.** Comparison of landfilled vs. diverted waste with as-is vs. should-be sorting.

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**Table 1.**

Should-be waste category definitions.

Waste Category	Description	Example Items	Disposal Method
MSW	Any item which could not be sorted into mechanical recycling, RMW, industrial composting, advanced recycling, or sterilization streams	Plastic bags, IV tubing, soiled patient care items, wrappers	Landfilled
RMW	Items soaking in hazardous bodily fluids; items capable of producing a puncture wound	Blood, sputum & bodily secretions; needles, glass	Autoclaved then landfilled
Mechanical Recycling	Unsoiled paper products, aluminum cans, plastic #1	Cardboard, plastic water bottles, Protected Health Information (PHI)	Mechanically recycled
Industrial Composting	Post-consumer organic material	Food, soiled paper products, paper food packaging	Composted
Advanced Recycling	Clean patient-care plastics #2, #4, #5, #6 and proprietary plastic packaging	Urinals, disposable isolation gowns, condom catheter packaging	Chemically recycled
Sterilization	Unopened and unused single-use items from patient isolation rooms	Unopened saline flushes, alcohol wipes, gauze	Decontaminated with H <sub>2</sub> O <sub>2</sub> and reused

Notes: MSW is municipal solid waste, RMW is regulated medical waste. The descriptions refer to the inclusion criteria set by our hospital system's vendors.

**Table 2.**

Waste categorization by weight (kg) and percent total (%) collected as-is vs. as should-be.

Categories	As-Is Sorting			Should-Be Sorting			Absolute Change in Percent
	Weight (kg)	Weight per Patient (kg)	Percent Total	Weight (kg)	Weight per Patient (kg)	Percent Total	
<b>Municipal Solid Waste</b>	<b>80.4</b>	<b>4.0</b>	<b>82.6%</b>	<b>58.2</b>	<b>2.9</b>	<b>60.3%</b>	<b>- 22.3%</b>
MSW containers	75.8	3.8	78.0%	58.2	2.9	60.3%	- 17.5%
Tray Waste	4.6	0.2	5%	0.0	0.0	0.0%	- 4.8%
<b>Regulated Medical Waste</b>	<b>13.8</b>	<b>0.7</b>	<b>14.2%</b>	<b>14.5</b>	<b>0.7</b>	<b>15.0%</b>	<b>0.8%</b>
RMW containers	11.7	0.6	12%	11.7	0.6	12.0%	0.1%
Sharps containers	2.8	0.1	3%	2.8	0.1	3.0%	0.0%
<b>Mechanical Recycling</b>	<b>3.1</b>	<b>0.2</b>	<b>3.2%</b>	<b>6.7</b>	<b>0.3</b>	<b>6.9%</b>	<b>3.7%</b>
PHI receptacles	2.0	0.1	2%	2.0	0.1	2.0%	0.0%
Recycling containers	1.1	0.1	1%	4.7	0.2	4.9%	3.7%
<b>Industrial Composting</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>11.4</b>	<b>0.6</b>	<b>11.8%</b>	<b>-</b>
<b>Advanced Recycling</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>5.3</b>	<b>0.3</b>	<b>5.5%</b>	<b>-</b>
<b>Sterilization</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>0.5</b>	<b>0.0</b>	<b>0.5%</b>	<b>-</b>
<b>Total</b>	<b>97.3*</b>	<b>4.9</b>	<b>100.0%</b>	<b>96.5*</b>	<b>4.8</b>	<b>100.0%</b>	<b>-</b>
Total landfilled waste	94.2		96.8%	72.7		75.3%	- 21.5%
Total diverted waste	3.1		3.2%	23.5		24.7%	21.5%

Notes: There were 20 patients on the unit over each of the 24-hour periods of collection allowing for per-patient calculations.

\* The 0.81 kg discrepancy between total weight in the as-is scenario and should-be scenario is due to liquid waste which was disposed of prior to sorting into should-be categories. There was a total of 7,240 patient-days on the Neuro ICU unit during fiscal year 2021, translating to about 35,260 kg of waste generated annually. Any discrepancies in sums are due to rounding.

**Table 3.**

Comparison of annual CO<sub>2</sub> equivalents produced by processing of landfilled waste as-is vs. as should-be.

Waste Category	As-Is Sorting		Should-Be Sorting		Absolute Difference in CO <sub>2</sub> e (mTPY)	Percent Change in CO <sub>2</sub> e
	CO <sub>2</sub> e (mTPY)	Percent Total	CO <sub>2</sub> e (mTPY)	Percent Total		
MSW	45.7	38.2%	33.1	29.9%	- 12.6	- 27.6%
RMW	74.0	61.8%	77.5	70.1%	3.5	4.7%
<b>Total</b>	<b>119.7</b>	<b>100.0%</b>	<b>110.6</b>	<b>100.0%</b>	<b>- 9.2</b>	<b>- 7.7%</b>

Notes:

mTPY = metric tons per year

CO<sub>2</sub>e = CO<sub>2</sub> equivalents, calculated by M+ WasteCare calculator as: CO<sub>2</sub> emissions + (28\*CH<sub>4</sub> emissions). These emissions reflect the processing of this waste including landfilling of MSW and autoclaving followed by landfilling of RMW. The calculations are made with the assumption that 44 kwh/ton of electricity are required to autoclave RMW. Per the Mazzetti M+ WasteCare Calculator, RMW generates 14.7 TPY of CO<sub>2</sub>e per ton of waste processed vs. MSW which generates 1.56 TPY of CO<sub>2</sub>e per ton of waste processed.

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**Table 4.**

Sensitivity analysis modeling how allocating varying proportions of RMW to MSW alters GHG emissions.

	Percent of RMW allocated to MSW	Resultant MSW emissions (mTPY CO <sub>2</sub> e)	Resultant RMW emissions (mTPY CO <sub>2</sub> e)	Resultant MSW + RMW emissions (mTPY CO <sub>2</sub> e)	Absolute percent change in emissions from baseline
Baseline	0%	0.0	74.0	74.0	0.0%
Modeled cases	10%	0.8	66.6	67.4	- 8.9%
	20%	1.6	59.2	60.8	- 17.9%
	30%	2.4	51.8	54.2	- 26.8%
	40%	3.2	44.4	47.6	- 35.8%
	50%	3.9	37.0	40.9	- 44.7%
	60%	4.7	29.6	34.3	- 53.6%
	70%	5.5	22.2	27.7	- 62.6%
	80%	6.3	14.8	21.1	- 71.5%
	90%	7.1	7.4	14.5	- 80.4%
	100%	7.9	0.0	7.9	- 89.4%

Notes:

mTPY = metric tons per year

CO<sub>2</sub>e = CO<sub>2</sub> equivalents, calculated as CO<sub>2</sub> emissions + (28\*CH<sub>4</sub> emissions). This sensitivity analysis considers total CO<sub>2</sub> equivalents produced in scenarios of increasing diversion of the 13.8 kg of as-is RMW to MSW. A sensitivity analysis was performed because as we were unable to open and sort RMW and sharps containers to define the true should-be RMW quantity in our study.