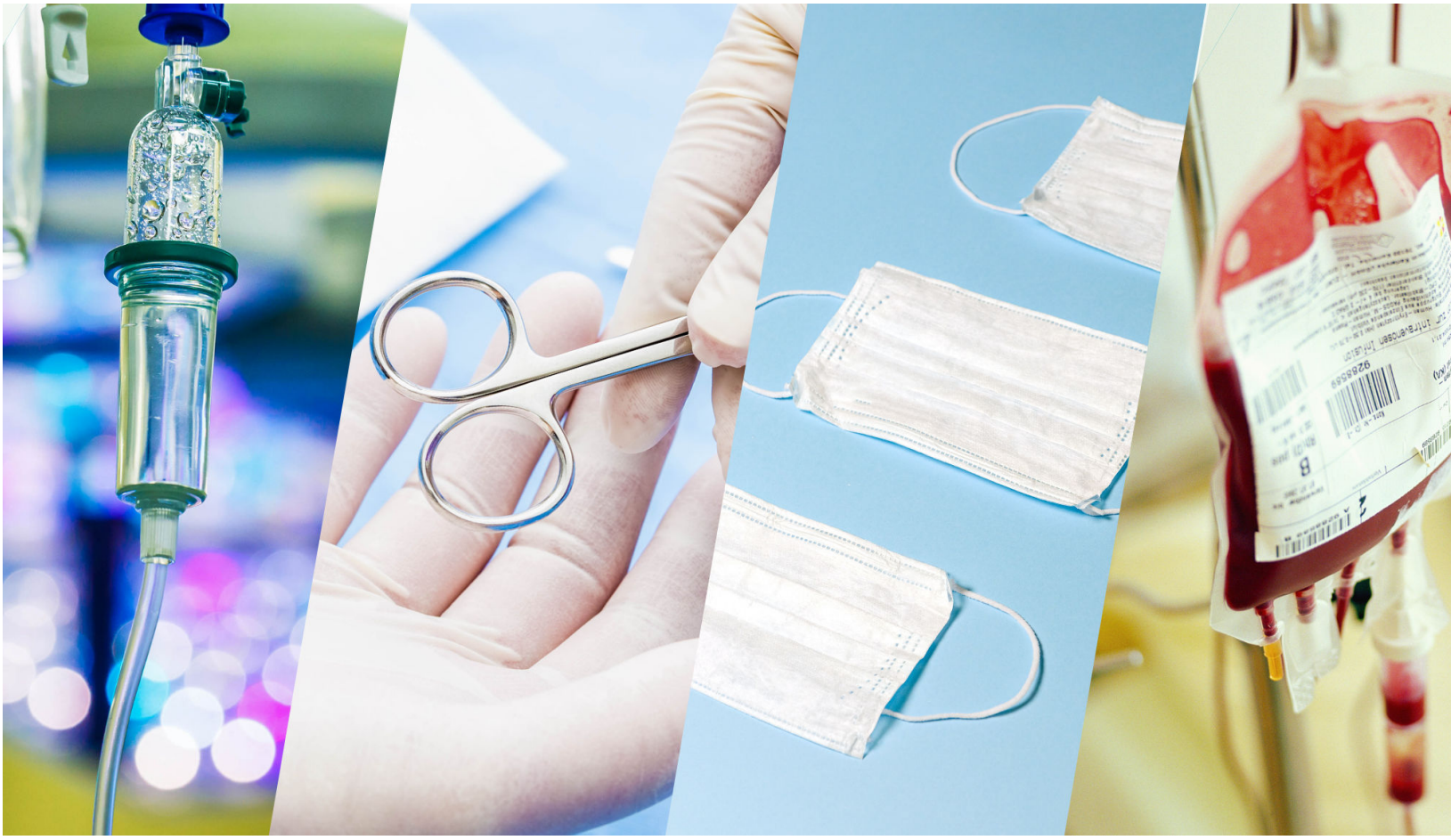
The Canadian Coalition for Green Health Care
Coalition canadienne pour un système de santé écologie

CENTRE FOR SUSTAINABLE HEALTH SYSTEMS
Redefining sustainable healthcare

A circular economy model for hospital generated PPE and medical single use plastic waste: Demonstrating opportunities for reduction and reuse.

Literature Review and Environmental Scan of Medical Single Use Plastic (SUP) Waste, including Personal Protective Equipment, in the context of a circular economy for health care



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Abstract

The healthcare sector has increasingly contributed to plastic pollution through the consumption of disposable personal protective equipment (PPE) and other medical single-use plastic (SUP) products (Klemes et al., 2020; Rizan et al., 2020a; Rizan et al., 2020b). Shifting from a linear economy to a circular economy (CE) model for managing the products that currently end up as hospital-generated waste has potential to mitigate some of the environmental harms associated with manufacturing, using, and disposing of medical SUPs (MacNeill et al, 2020). In particular, CE may help to reverse the current trajectory toward single use medical products and supplies through a renewed emphasis on long-lasting design, reuse, remanufacturing and refurbishment to maintain products and materials in their highest value state for as long as possible.

While the circular economy has its limitations, the approach can be used to support environmental sustainability in our healthcare system. The key general conclusion from this report is that a multitude of strategies exist for reducing and reusing PPE and medical SUP, where recycling SUPs and PPE should be practiced after the options to reduce and reuse have been optimized. Many of these strategies are both feasible and effective in generating cost savings and environmental benefits. There are also many opportunities emerging from the pandemic to reprocess and recycle PPE. Considering that the usage and demand for PPE and other SUPs are only expected to grow around the world, the need for the healthcare system to scale down their environmental impact cannot be understated (Rizan et al., 2020a). The waste hierarchy of reducing, reusing, and recycling, alongside key CE principles, can help guide these efforts. The health care sector however is unique in that the overarching goal of a healthcare system should be on preventing illness and ensuring a healthy population which requires fewer health services.

Résumé

Le secteur de la santé contribue de plus en plus à la pollution plastique à travers la consommation d'équipements de protection individuelle (EPI) jetables et d'autres produits médicaux en plastique à usage unique (Klemes et al., 2020 ; Rizan et al., 2020a ; Rizan et al., 2020b). Passer d'un modèle d'économie linéaire à un modèle d'économie circulaire, afin de gérer les matières générées par les hôpitaux qui finissent actuellement à l'enfouissement, a le potentiel d'atténuer certains des impacts environnementaux associés à la fabrication, à l'utilisation et à l'élimination des plastiques médicaux à usage unique (MacNeill et al, 2020). Plus précisément, l'économie circulaire peut contribuer à inverser la trajectoire actuelle des produits médicaux à usage unique en mettant à nouveau l'accent sur la conception durable, la réutilisation, le reconditionnement et la remise à neuf, afin de maintenir les produits et les matériaux dans leur état de plus grande valeur aussi longtemps que possible.

Bien que l'économie circulaire ait ses limites, cette approche peut être utilisée pour soutenir la durabilité environnementale de notre système de santé. La principale conclusion de ce rapport est qu'il existe une multitude de stratégies pour réduire et réutiliser les EPI et les plastiques médicaux à usage unique, où le recyclage de ces plastiques et des EPI doit être pratiqué après que les options de réduction et de réutilisation ont été optimisées. Nombre de ces stratégies sont à la fois réalisables et efficaces pour générer des économies de coûts et des avantages environnementaux. La pandémie offre également de nombreuses possibilités de retraitement et de recyclage des EPI. Étant donné que l'utilisation et la demande d'EPI et d'autres plastiques médicaux à usage unique devraient croître dans le monde entier, la nécessité pour le système de santé de réduire son impact environnemental ne peut être sous-estimée (Rizan et al., 2020a). La hiérarchie des modes de gestion des matières résiduelles, à savoir la réduction, la réutilisation et le recyclage, ainsi que les principes clés de l'économie circulaire, peut contribuer à guider ces efforts. Le secteur de la santé est toutefois unique en ce sens, puisque que l'objectif primordial d'un système de soins de santé devrait être de prévenir les maladies et de garantir une population en bonne santé qui nécessite moins de services de santé.

Executive summary

This rapid review generates an overview of current reduction, reuse, and recycling options for PPE and other medical SUPs in healthcare, and identifies factors known to influence these opportunities. It investigates the regulatory and economic conditions under which medical SUPs can be reduced, reused, and recycled. It explores CE as a potential opportunity for the healthcare sector to support the reduction of medical plastic waste and its subsequent negative effects on human and environmental health.

Given the continued rise in demand for PPE and its associated environmental harms, it has been suggested that COVID-19 can act as a catalyst for changes in plastic waste management in healthcare (Klemes et al., 2020; Sharma et al., 2020). One way of achieving this that has gained interest is by shifting from a linear model to a circular economy (CE) model in the healthcare sector (Kane et al., 2018; Wuyts et al., 2020; Fadare & Ozoffo, 2020; MacNeill et al., 2020; Guzzo et al., 2020; Ritchie, 2021). CE has particular potential in helping to reverse the current trajectory toward single-use medical products and supplies through a renewed emphasis on long-lasting design, reuse, remanufacturing and refurbishment to maintain products and materials in their highest value state for as long as possible.

Yet CE also faces limitations. Sustainability in the sense of securing social, economic and environmental benefits across and within generations is not assured by the narrow ambition of CE, and the net global environmental benefits from any one CE effort must be assessed on a case-by-case basis. As well, the CE framework fails to consider the importance for healthcare sustainability of *avoiding* use. Thus, CE should be understood as "one among several solutions" (Geissdoerfer et al., 2017) for fostering the sustainable management of healthcare products.

Given the insufficiency of CE as a conceptual framework for healthcare sustainability, and the limited research exploring and measuring the impact of CE efforts in healthcare, this review adopts the traditional waste hierarchy – reduce use, reusing existing products to the maximal extent, and recycle – as a framework for discussion of results, integrating CE principles within this framework as and where appropriate. These three elements of the waste hierarchy have been applied successfully in numerous cases within healthcare. A summary of strategies, emerging opportunities, and challenges for each element is listed below:

Reduce

- Many efforts to reduce medical waste originate from the operating room, where a significant volume of waste from SUPs and PPE is generated. Replacing plastic wrap with rigid metal containers and re-designing surgical custom packs and instrument sets to remove unnecessary materials are two cost-effective and environmental advantageous waste reduction strategies (Campion et al., 2015; Albert & Rothkopf, 2015).

- **Choosing Wisely** is a growing movement with the aim of creating a more sustainable healthcare system where overuse is eliminated (McGain et al., 2020). This is accomplished

by reducing the number of unnecessary medical tests, treatments, and procedures, which has effectively prevented the wastage of healthcare resources such as single-use catheters (CIHI, 2017).

- The low-cost to purchase and dispose some SUPs such as syringes presents a challenge to develop cost-effective waste reduction strategies for these devices. There is also a lack of sustainable alternatives for these devices which serve the same function while maintaining the same levels of safety (Kane et al., 2018). As a result, reduction efforts should focus on changing the delivery mechanism of the device or changing the equipment associated with its use, as in the case of pre-filled syringes (Cheetham & Johnson, 2013).

Reuse

- Reuse is recognized as a necessary component to the CE, by keeping products in use or lengthening their lifespan. **Reprocessing** is the most common strategy to reuse PPE where devices are decontaminated through physical and chemical means. The three main factors which influence the adoption of this practice are the environmental impact, cost, and safety (Kane et al., 2018; Baker et al., 2021).

- **Reusable gown use**, in particular, is emphasized as a way to achieve cost savings, decrease waste, and improve supply chain resilience without compromise to safety (Baker et al., 2020). They can ensure a stable supply of PPE and build resilience in the future of healthcare to be better prepared for future crises.

    1. **Environmental impact.** The environmental advantage associated with switching from SUDs to reusables is well-established (Sanchez et al., 2020; Donahue et al., 2020; Sherman et al., 2018; Eckelman et al., 2012). Amongst PPE, the environmental impact of reusable gowns is the most extensively documented.
    2. **Cost.** Due to their low purchasing price and the absence of sterilization and maintenance costs, SUDs are often mistaken as being more cost-effective (Siu et al., 2017). However, the lifetime cost of reusables is generally lower than SUDs (Sanchez et al., 2020).
    3. **Safety.** Reusable forms of PPE, including reusable gowns and elastomeric respirators are readily available, used, and considered safe alternatives to their disposable varieties (PHO, 2020). The reprocessing of single-use PPE remains a topic of exploration.

- **Other strategies for reuse include:**

    - **Remanufacturing or refurbishment**, where a device is physically restored back to its original state or one of lower quality, respectively. It typically occurs for

expensive, long-lasting medical devices such as patient monitors. Devices are physically restored back to their original state through the replacement of non-functional parts, for example.

- **Repair and maintenance**, which involve routine checkups or cleaning. It extends the lifetime of products. For reusable gowns, this could involve monitoring the number of uses and replace fastening ties. An example is the practice at offsite laundries where staff inspect and repair reusable surgical gowns as required.

- **Redistribution** through mobile medical units and platforms for device circulation maximizes the lifespan of devices and reduces production of new devices, in both a sustainable and cost-effective way for facilities and manufacturers (Guzzo et al., 2020).

- **Product as a service or 'servitzation'** also is evident with reusable gowns, where hosptials may have contracts with the laundry operation to 'lease' the reusable gowns.

- **Challenges to reuse.** Concerns with possible infection from improperly decontaminated reusable devices limits the reuse of medical devices (Kane et al., 2018). There is continued concern about the safety and effectiveness of SUD reprocessing and it is difficult to obtain reliable information on infections from reusing devices (Hailey et al., 2008; Upadhyay et al., 2007). On the other hand, there is evidence to suggest that some safety protocols that dissuade reusing devices are not founded on evidence of risk, resulting in increased waste generation (Sherman & Hopf, 2018). For non-critical devices (blood pressure cuffs, gowns, and reusable masks) at least, there is strong evidence to suggest they are safe when decontaminated appropriately and that reusable forms are appropriate (Sanchez et al., 2020; Gialluly et al., 2006; Sherman & Hopf, 2018; Baker et al., 2020).

- There is **no one-size-fits-all approach** for managing waste from the diverse types of medical SUPs. It is important to not generalize that SUPs are superior in terms of safety and cost or that reusables are superior in terms of environmental impact. This is because disposable products save the need for sterilization, but drive-up waste and emissions, while reusable products require high utilization rates in order to achieve cost and environmental savings. Reusable devices must be reused a certain number of times to offset the cost and environmental impact of producing them (Miller, 2020). Healthcare facilities, or their service provider, must track the number of times a device is used. If it is not possible to reuse a device enough times, then a disposable product may be better.

- Out of the pandemic, there are growing sentiments that more must be done to develop reprocessing standards and enforce adherence to current standards for PPE and medical devices (Hancock-Howard et al., 2021). In Canada, there is also a limited reprocessing industry and a lack of accreditation and training for reprocessing single-use devices (Hancock-Howard et al., 2021).

Recycling

- Around one-third of waste generated in Ontario hospitals may be recyclable (CCGHC, 2019), with plastics making up over half of this recyclable waste (McGain et al., 2015).

- Plastic is usually recovered through a process called **mechanical recycling** where a device is broken down into its individual components, which are then reconstituted into a useful application (Rhodes, 2019). **Chemical recycling** is a method of recycling that aims to change the material structure of plastics wastes, purifying and breaking the plastic down into smaller polymer chains or its monomer constituents; the technology is currently in small scale or pilot phase with uncertain future potential.

- Recycling companies may retrieve obsolete devices from healthcare facilities, harvest functional parts, and recycle non-functional parts. Device manufacturers may also develop **take-back schemes** where they implement infrastructure to properly sort and collect discarded devices in healthcare facilities. These devices are then retrieved by the manufacturer to be recycled. This typically occurs for sharps, and has started to occur with PVC intravenous bags, oxygen masks, and oxygen tubing waste.

- Recycling generates smaller cost and environmental savings than reducing and reusing (Miller, 2020).

- **Challenges for recycling**

    - To date only about 8% of plastics used world-wide are have been recycled (Environmental Defence, 2018).
    - Recycling rates are limited by inadequate recycling infrastructure, staff knowledge of waste management and safety concerns, product design, and a lack of a profitable recycling market.
    - Recycled products are generally lower quality, and more expensive to manufacture than products made of virgin plastic materials (Rhodes, 2019). Therefore, it is more cost-effective for companies to manufacture new products made from virgin plastics (Prata et al., 2019). As a result, there is a lack of profitable recycling market and few recyclers (Leissner & Ryan-Fogarty, 2019).

- Providing education to healthcare workers on how to properly sort general waste, biomedical waste, and recyclables has shown to be effective in increasing recycling rates (Wormer et al., 2013).
- Challenges also exist at the hospital site where in general there is limited room for additional recycling containers in the various departments, and lack of room to store collected recyclables at the loading docks.
- During the COVID-19 pandemic additional concerns about the infectious nature of the PPE waste in particular required decontamination procedures to be investigated. Some of the PPE plastic waste, such as surgical masks, contain multiple material types (plastic, bands and metal) which need to be separated by hand before recycling. Decontamination of this waste prior to handling at the recycling site is therefore required adding to the cost. In other cases, for example PVC recycling, no separation by hand is needed as the PVC medical single use products are all one material type (PVC) and the collected materials could go directly to the recycling process without the need for decontamination.

- There is also a need to rethink product design to ensure SUPs are not made of mixed plastics (which pose a challenge to mechanical recycling) and that SUPs can be easily disassembled into individual constituents. For surgical masks, this means that the aluminum wire and bands need to be designed to be easily removed (Rodriguez et al., 2021).

Improving the sustainable management of healthcare products

Reducing, reusing, and recycling are necessary components in the sustainable management of healthcare products. To enable these three processes, broader system re-design through the incorporation of lifecycle thinking is necessary. Lifecycle thinking considers the environmental impacts of products from conception to end-of-life, including material selection, manufacturing, distribution, and end-of-life processes (Moultrie et al., 2016). It plays a pivot role in changing consumption patterns, industry behaviour, and the design of products, which are necessary to reduce supply chain impacts (Geisendorf & Pietrulla, 2018; Miller et al., 2020).

It has been argued that the pathway for a successful transition to the CE in the healthcare sector requires the engagement of hospitals, policymakers, and manufacturers (MacNeill et al., 2020). Necessary actions for these stakeholders identified in this report are as follows.

1. **Hospitals** can adopt sustainable procurement, where they purchase products or services from manufacturers who are able to demonstrate lower environmental impacts. This pushes innovation amongst manufacturers and drives them to adopt more sustainable practices. They can also ensure the appropriate segregation of

plastic for recycling through an easy-to-use recycling program and proper waste sorting education.

2. **Policymakers** could implement regulations to incentivize the adoption of sustainable business models and principles. Current regulations incentivize device manufacturers to produce SUDs, encouraging the profit-driven linear business model in the medical device industry. Instead, regulations should serve to financially incentivize manufacturers to implement sustainable business models, with some potential for extended producer responsibility (EPR) arrangements and servitization (Singh et al., 2020). These approaches may encourage manufacturers to design products that are durable and long-lasting, fostering innovation, circular product design, and maximal usage of resources (MacNeill et al., 2020).

a. Servitization – Manufacturers provide access to equipment or products through short-term or long-term renting and leasing contracts, while also providing continuous maintenance and remanufacturing services.

b. Extended Producer Responsibility - Manufacturers are responsible for the collection, reuse, and recycling of their products. This shifts the responsibility of end-of-life management of discarded products and packaging from healthcare facilities to manufacturers.

3. **Manufacturers** play an important role in supporting the reuse and recycling of SUPs through adopting **circular design principles** (Kane et al., 2018). For example, reusable devices must be designed to be durable for repeated usages and to survive mechanical or chemical damage. Lifecycle assessments are recommended to determine the environmental impacts of recycling particular devices to ensure that it is able to offset the environmental impact from the process (Wyssusek et al., 2019). They are also recommended to incorporate sustainability into product design (Leiden et al., 2020; Leissner & Ryan-Fogarty, 2019; Moultrie et al., 2016; Sousa et al., 2020).

A limitation to the CE is the restrictions on the amount and types of SUPs that can be recycled (Sherman et al., 2020). Recycling relies on the input of a steady stream of waste. This demand for waste proliferates the linear economy through the extraction of natural resources to create new plastic materials (Prata et al., 2019). To implement a CE model of managing healthcare waste, reducing and reusing existing plastic waste must be prioritized. Furthermore, using fewer fossil fuels and raw materials are required to achieve circularity; both are challenging feats in the current landscape of the plastic industry.

The key general conclusion from this report is that a multitude of strategies exist for reducing, reusing, and recycling SUPs and PPE. These strategies are both feasible and effective in generating

cost savings and environmental benefits. There are also many opportunities emerging from the pandemic to reprocess and recycle PPE. Considering that the usage and demand for PPE and other SUPs are only expected to grow around the world, the need for the healthcare system to scale down their environmental impact cannot be understated (Rizan et al., 2020a). The waste hierarchy of reducing, reusing, and recycling, alongside key CE principles, can help guide these efforts.

Yet CE also faces limitations. Sustainability in the sense of securing social, economic and environmental benefits across and within generations is not assured by the narrow ambition of CE, and the net global environmental benefits from any one CE effort must be assessed on a case-by-case basis. As well, the CE model fails to consider the question of *avoiding* use, which is a core principle of healthcare sustainability. Thus, CE should be understood as "one among several solutions" (Geissdoerfer et al., 2017) for fostering the sustainable management of healthcare products. Given the insufficiency of CE as a conceptual framework for healthcare sustainability, and the limited research assessing the impact of CE efforts in healthcare, this review adopts the traditional waste hierarchy – reduce, reuse, recycle – as a framework for discussing results, integrating CE principles within this framework as and where appropriate.

1. Introduction

The COVID-19 response has led to an increased production and consumption of personal protective equipment (PPE) (Haque et al., 2021). The Canadian healthcare sector and general public were estimated to add 63,000 tons of COVID-19 related PPE waste to landfills over the first year of the pandemic (Science and Economic Development Canada, 2020b). The English National Health Service used three billion items of single-use PPE during the first six months of the pandemic, an excess of 1.8 billion compared to average (Rizan et al., 2021).

A large portion of these items consists of single-use gloves, masks, and aprons made up of predominately plastic polymers, such as polypropylene and polyolefins (Farrell & Smyth, 2021; Science and Economic Development Canada, 2020b). Single-use PPE is a form of medical single-use plastic (SUP). These are medical devices made of plastic materials which are intended by manufacturers to only be used once on a single patient before being disposed, and do not achieve their intended function through pharmacological means (Health Canada, 2007; Health Canada, 2016). SUPs may also be referred to as single-use devices (SUDs); both terms will be used in this paper.

Over the past 50 years, the growing demand and reliance on SUPs in the healthcare sector has resulted in the medical device industry adopting a linear economy business model (Rizan et al., 2020a; Moultrie et al., 2016). In this model, devices are manufactured, used once, then landfilled. Some types of hospital generated waste pose an infection risk and must be incinerated before being landfilled (Gautam et al., 2010). Thus, throughout the supply chain, significant volumes of greenhouse gas emissions (GHGs) and other environmental contaminants are released from manufacturing, transportation, packaging, and waste management (Cimprich et al., 2019).

Given the continued rise in demand for PPE and its associated environmental harms, it has been suggested that COVID-19 can act as a catalyst for changes in plastic waste management systems within healthcare (Klemes et al., 2020; Sharma et al., 2020). One way of achieving this that has gained interest is by shifting from a linear model to a circular economy (CE) model in the healthcare sector (Kane et al., 2018; Wuyts et al., 2020; Fadare & Ozoffo, 2020; MacNeill et al., 2020; Guzzo et al., 2020; Ritchie, 2021).

To inform policy interest in the potential for CE in healthcare in Canada, we conducted a literature review and environmental scan as part of the project on medical SUPs led by the Canadian Coalition for Green Health Care (See Appendix A for full details). This review serves to: (1) generate an overview of current reduction, reuse and recycling options for PPE and other medical single-use plastics (SUPs) in healthcare; and (2) identify factors known to influence these opportunities. Throughout the paper, case studies seek to illustrate key examples of reduction, reuse, and recycling initiatives and their impacts within healthcare settings with particular focus on opportunities for PPE emerging during the COVID-19 pandemic. Additionally, we consider the

regulatory and economic conditions under which SUPs can be reduced, reused, and recycled in healthcare.

The potential of CE

The CE concept highlights "the linear and open-ended characteristics of contemporary economic systems," which contrast with the fact that the earth is a largely "closed and circular system with limited assimilative capacity" (Geissdoerfer et al, 2017). Thus, a CE aims to slow, close or narrow resource and energy loops, to reduce resource inputs and waste and emission leakages; traditional recycling, with its focus on raw material utilization, is downgraded in CE (Korhonen et al, 2018). CE highlights the importance of long-lasting design, reuse, remanufacturing and refurbishment to maintain products and materials in their highest value state for as long as possible. CE also highlights the potential of a new consumption culture - a sharing economy that maximizes use of existing products, for example through car sharing instead of car ownership or space sharing instead of hotels. The term 'dematerialization' can be used to capture some of these aims; it describes efforts to minimize resource inputs through efficiencies (i.e., reducing mass or material types in products), digitization (e.g., delivering music digitally rather than through physical devices such as CDs or records) or servitization (i.e., delivering a product as a service).

Interest in the idea of a "circular economy" has grown since the late 1970s, attracting considerable policy attention in recent decades. Multiple countries have introduced legislation and strategies to advance a CE, including Germany, China, Japan, and the EU (Geissdoerfer et al, 2017; Delphi Group, 2017). In Canada too, there is considerable public policy interest. In 2016, Ontario passed a comprehensive circular economy law, becoming the first jurisdiction in the Americas to do so (Cocker and Graham, 2020). In 2018, the federal government developed a national strategy to promote the CE and reduce the environmental impact of plastics (Environment and Climate Change Canada, 2018).

These policy commitments are highly relevant to medical SUP. In 2020, the English National Health Service (NHS) became the first national healthcare system to commit to a target of net-zero carbon emissions by 2045 (for directly and indirectly controlled emissions), with CE identified as a support to this ambition (NHS, 2020). Meanwhile, Canada's federal government has committed to achieving a sustainable recovery from the COVID-19 pandemic, including through the development of environmentally preferable PPE solutions such as recycling technologies and compostable alternatives (Science and Economic Development Canada, 2020a).

Yet while the CE holds potential, it has important limitations. The concept has been promoted principally by practitioners, including governments, businesses and associated think tanks. The research literature remains sparse. Indeed, according to Korhonen and colleagues (2018), the CE concept is "superficial and unorganized …. a collection of vague and separate ideas from several fields and semi-scientific concepts" (Korhonen et al, 2018).

One outcome of limited research is that the sustainability benefits of CE are more often assumed than demonstrated. This is partially because CE and sustainability are not synonymous. Sustainability has a broad scope, aiming at benefiting the environment, economy and society while supporting reflexivity about what is to be sustained, for how long and for whose benefit. CE, by contrast, has a narrower ambition, focusing primarily on economic benefits with expected environmental improvements and limited attention to social aspects. Relatedly, while the primary agents of the CE are seen to be governments and businesses, the aim to achieve sustainability anticipates that all stakeholders will share in defining priorities (Geissdoerfer et al, 2017). Prospects for a sharing economy illustrate the implications of these differences. A sharing economy can be generated by and sustain very different socio-economic arrangements, including monopolistic corporate control at one extreme and collective social agency at the other (Frenken, 2017). Thus, the CE model is insufficient to inform and guide which social, economic and environmental outcomes will or should prevail.

A further challenge relates to prospects for *net* global environmental benefits from any one CE effort, given the potential to shift rather than reduce harms over time and space, and the established paradox of efficiency, such that greater overall resource utilization and pollution may arise even as per unit resource use and pollution are reduced. Thus, "the sustainability contribution of circular economy projects is a question that needs a case-by-case analysis" (Korhonen et al, 2018).

Both the potential and the limitations of CE have important implications for health policy. Positively, CE brings needed attention to the potential to reverse the trajectory toward single use medical products and supplies in healthcare. As MacNeill and colleagues (2020) have argued, there is a need to extend product longevity by "designing for durability and developing reuse systems to maximize product life." More negatively, a narrow focus on CE detracts from a core principle of healthcare sustainability, which is to avoid the use of medical products by prioritizing the promotion of health, including through investments in the social determinants of health as well as prevention, health promotion and disease management (MacNeill et al., 2021; Mortimer et al, 2018). As well, sustainable healthcare requires the appropriate use of healthcare products and services. Yet we know that a non-negligible portion of the health products and services used by Canadians are unnecessary (CIHI, 2017), creating clinical risk and environmental burden without good cause. A focus on CE is therefore insufficient to improve the sustainability of medical product management in healthcare.

The limitations of CE do not mean that the agenda should be dismissed. Rather, CE should be understood as "one among several solutions for fostering a sustainable system" – not the only or necessarily the best (Geissdoerfer et al., 2017). In light of the insufficiency of CE as a conceptual framework for guiding the sustainability of SUP in healthcare, and the limited research exploring and measuring the impact of CE efforts in healthcare, this review adopts the traditional waste hierarchy – reduce, reuse, recycle – as a framework for discussion of results, integrating CE principles within this framework as and where appropriate.

2. Methods

This review of academic literature was informed by the rapid review framework recommended by Tricco et al. (2017). Compared to a systematic review, the methodology in a rapid review is streamlined in order to shorten the timeline to complete the review. In line with the recommended guidance, the following measures were taken to streamline the process: using a limited rather than exhaustive range of search terms; limiting the number of electronic databases and websites searched; and using one reviewer to select studies and extract data. The review focused on published academic peer-reviewed literature and grey literature.

Relevant studies were identified using PubMed and reference lists of eligible articles. English language articles published from inception of the databases to June 2021 were included. The search strategy involved combinations of the following keywords: i) medical OR health AND ii) reusable OR single-use plastics OR single-use device AND iii) sustainable OR environment OR waste AND iv) circular economy. Both peer-reviewed primary and secondary articles were included with no restriction on the type of study design. Additionally, while the focus of this review is on SUPs, we retained literature on non-plastic SUDs when it was identified to be relevant to our research objectives. For example, single-use surgical instruments are often made of metal. Any articles that described opportunities to reduce, reuse, or recycle any type of medical SUP or SUD in support of sustainability imperatives were included.

Some efforts to reduce the use of single-use PPE or to reuse single-use PPE (e.g., wearing a mask for multiple shifts or reusing expired PPE) arise under crisis conditions that permit safety and quality standards to be reduced. These strategies are excluded from this review as they were optimization strategies during times of shortened supplies and are understood to be sub-optimal (CDC, 2020; Ontario Health, 2020). This means that the strategies identified in this review could be continued in non-crisis contexts.

We also conducted a grey literature search to ensure this review captured opportunities for recycling, reuse, and reduction initiatives for PPE emerging from the COVID-19 pandemic. This search aimed to illustrate ways in which developments in PPE production and distribution during the COVID-19 pandemic reflect the opportunities and challenges apparent in the literature.
To accelerate the research process, we restricted the grey literature search to Canada. In March 2021, we started with a Google search for opportunities emerging in Canada, and then refined our approach using media and select organizations (e.g., research/innovation funding bodies or government agencies promoting innovation in this area). Grey literature was identified using the following keywords: reusable PPE/masks, Canada, innovative PPE. Articles which identified and described PPE recycling, reuse, and reduction opportunities and initiatives in Canada were included; preference was given to those with a focus on initiatives emerging from the COVID-19 pandemic.

3. Results

235 articles were retrieved from the academic literature search. Based on the initial screening of the title and abstract, 53 academic articles were selected for further review. After a full-text assessment, only 37 articles met the inclusion criteria and were selected for the final analysis. The reference lists of these eligible studies were searched by hand, resulting in an additional 49 publications identified. The final set of publications consisted of 86 articles.

The year of publication for the final set of articles ranged from 2002 to 2021. The assortment of studies included 3 environmental scans, 11 literature reviews, 3 systematic reviews, 1 scoping review, 5 qualitative studies, 30 qualitative studies (case studies, reports, and commentaries), 17 quantitative studies, and 16 life-cycle assessments.

Several articles (n=36) were concerned with waste management strategies for a specific medical device. Of these articles, 17 articles focused primarily on reuse or recycling strategies for PPE, including masks, gloves, and gowns. Other devices include blood pressure cuffs (n=2); dialyzers (n=1); intermittent catheters (n=4); infant formula bottles (n=1); laryngeal mask airways (n=1); laryngoscope handles and blades (n=1); syringes (n=2), ureteroscopes (n=1); vagina specula (n=1); and surgical instruments (n=6).

Most of the articles (n=31) focused on the conditions under which medical devices can be reused either by switching from disposables to reusable devices; through reprocessing; or through other strategies such as remanufacturing or redistribution. Furthermore, a significant number of studies (n=25) were focused on opportunities to reduce waste in the operating room; these constitute the majority of the waste reduction strategies discussed in this paper. A handful of other studies (n=5) on reduction were included, specifically focused on syringes and catheters. Recycling strategies for recycling various SUPs were also reported (n=9). Lastly, while not specific to medical waste, four articles which discussed plastic waste in the context of the COVID-19 pandemic were included due to discussion on broader plastic waste reduction strategies such as chemical recycling. The remainder of the articles (n=12) were concerned with conceptualizing these reduce, reuse, recycling, or redesign strategies through discussion of the circular economy. Through the grey literature search, articles were identified on the latest research and development initiatives to reduce PPE-related waste in Canada (n=14).

The findings of this review are organized in accordance with the waste hierarchy: reduce, reuse, and recycle. These principles represent a hierarchical order for how resources should be utilized to achieve the greatest sustainability and cost savings (Miller, 2020). The top priority of sustainable efforts should be to reduce production and consumption of new SUPs. In doing so, the extraction of new raw materials is prevented and the impact of environmental harms which largely stem from manufacturing and transportation are cut down. If reduction is not feasible, then reuse is the next desirable option. For medical devices, reuse can occur in a variety of ways from in-hospital or third-party reprocessing; remanufacturing or refurbishment; repair and maintenance; and

redistribution. When reuse is no longer possible, efforts turn to recycling SUPs into new useful applications.

4. Reduce

Prior to the COVID-19 pandemic, SUP usage and sustainability efforts were concentrated in the operating room (OR), making the OR an exceptional case study for how to reduce waste from SUPs in the healthcare sector (Wyssusek, 2019). Currently, there is a growing movement to focus on sustainability efforts within clinical care by adopting evidence-informed waste prevention practices developed by organizations such as Choosing Wisely (McGain et al., 2020; Sherman et al., 2020). However, the single-use nature of these devices is a challenge to developing waste reduction strategies. This section proceeds as follows. First, we provide an overview of established approaches to reduce waste in the OR. Followed by a discussion on current opportunities to further reduce waste through Choosing Wisely and lastly, we identify challenges to waste reduction.

4.1 Current approaches: Operating room

The OR generates up to one-third of a hospital's waste through the consumption of disposable surgical supplies, PPE, and drapes (Stall et al., 2013). Surgical supplies are also covered with disposable polypropylene wraps to ensure sterility, which is not widely recycled (Albert & Rothkopf, 2015). One strategy that has been implemented successfully to reduce the waste from disposable polypropylene wraps is storing surgical items in rigid metal containers (Lee & Mears, 2012). This reduces usage of wraps by 70%, with economic effects paying off with long-term use over 3 to 4 years (Saver, 2011).

Surgical Trays

The re-design of surgical trays and custom packs is one of the most widespread and well documented examples of medical waste reduction. Surgical materials are sorted and bundled together in "custom packs" containing bowls, drapes, cautery items, gowns, and other materials to save time for healthcare workers (Leiden et al., 2020). Once the pack has been opened, all items must be discarded (whether used or not) due to infection concerns after the operation is completed. Complex surgeries, in particular, routinely generate significant amounts of unnecessary waste from unused items (Campion et al., 2015; Zygourakis et al., 2016). To prevent this, these bundles can be re-designed with input from healthcare providers into "new green custom packs" (Campion et al., 2015). By working with surgeons, some hospitals have been able to identify which materials go unused and which materials are considered essential for a given procedure (Donmez et al., 2019).

A multitude of studies have reported major reductions in waste and expenditure by limiting the materials used in the OR. Optimizing surgical trays for pediatric surgeries in one US hospital eliminated around 60% of instruments per tray, resulting in an overall reduction of 1826

instruments from rotation and 45,856 fewer instruments processed per year (Farrelly et al., 2017). At another hospital where the removal of 18 disposable surgical instruments from a prepackaged tonsillectomy pack diverted 1.5 tons of waste and incurred $17,000 USD in savings annually (Penn et al., 2012). Similar results occurred with the removal of 22 commonly unused items in surgical packages for plastic and hand surgery, resulting in around $17,000 USD being saved (Albert & Rothkopf, 2015).

Reducing the number of surgical materials per operation using the input of surgeons is a proven waste and cost reduction strategy in the OR with great potential. Further considerations include designing surgical sets such that they do not become fully unsterile upon opening single packages, such as through sorting reusable surgical instrument sets into smaller boxes, and only opening packages when needed (Leiden et al., 2020).

4.2 Opportunity: Choosing Wisely

Choosing Wisely Canada (CWC) is a growing patient-centered, physician-led initiative with an emphasis on ensuring appropriate resource usage and creating a more sustainable healthcare system where overuse is eliminated (McGain et al., 2020). This is accomplished by reducing the number of unnecessary medical tests, treatments, and procedures (CIHI, 2017). For patients, unnecessary care provides limited clinical value and has the potential to cause harm. The organization has created a series of evidence-based recommendations to guide physicians on how to avoid unnecessary care without compromising patient safety. By collaborating with local jurisdictions, CWC managed to reduce unnecessary testing in emergency departments, urinary catheter use, preoperative testing, and blood transfusions (CIHI, 2017). By reducing unnecessary care, hospitals also prevent the wastage of healthcare resources associated with these tests and reduce expenditures, while improving quality of care.

Reducing catheter usage

Inappropriate catheter usage is one example of unnecessary care, which can lead to pain, discomfort, and infections for patients (Parker, 2017; Avery et al,. 2018). One hospital in Ontario reported that 69% of patients were catheterized despite not having an appropriate guideline-based reason (CWC, 2019). Seeing this opportunity to improve both patient care and efficiency in healthcare delivery, CWC developed standardized criteria for appropriate urinary catheter use (CWC, 2019). This resulted in a 50% reduction of the overuse of catheters sustained beyond one year. A substantial volume of waste could be prevented by implementing these guidelines, given that the United States alone produces up to 86 million pounds of waste annually from single-use catheters typically made of polyvinyl chloride (Sun et al., 2018).

4.3 Challenges

Kane et al. (2018) detail how the low-cost to purchase and dispose some SUPs, such as syringes and catheters, presents a challenge to develop cost-effective waste reduction strategies for these

devices. Also, there is a lack of sustainable alternatives to these products which can serve the same function while maintaining the same levels of safety and cost-effectiveness. They suggest that efforts to reduce the environmental impact of these devices should instead focus on changing the delivery mechanism of the device or changing the equipment associated with its use. One identified example is using pre-filled syringes (Atcheson et al., 2016). In an effort to reduce their carbon footprint, the English National Health Service (NHS) has shifted procurement of manual syringes to pre-filled syringes. The NHS uses around 411,000 pre-filled saline syringes a year, which are designed to save time by reducing the multiple steps involved in administering a manually prepared syringe from 14 to 6. In addition, pre-filled syringes reduce the need for ampoules, preparation needles, and alcohol swabs, meaning 411,000 less of each end up in the landfill each year, saving about 21% of CO2e per year (Cheetham & Johnson, 2013).

5. Reuse

A device is considered obsolete when it can no longer perform its function. For SUDs, this occurs once it has been used on a patient, becomes contaminated, and must be discarded. For reusable devices, this might occur when they become physically unable to function through damage or repeated usages. For some of these devices, it may be appropriate to undergo a process of "recovery" where it is restored to a previous state of functioning to be used again (Hollander et al., 2017).

The findings of this section are grouped into several categories of recovery identified by the literature as existing CE examples in the healthcare sector (Kane et al., 2018; Guzzo et al., 2020). These categories include: (1) reprocessing; (2) remanufacturing or refurbishment, where a device is physically restored back to its original state or one of lower quality respectively (3) repair and maintenance; and (4) redistribution of pre-owned equipment. These strategies are recognized as necessary components to a CE, either keeping a product in use or lengthening its lifespan. The majority of this section describes reprocessing, which is the most identified strategy to reuse PPE. Also, since the environmental impact, cost, and safety condition the adoption of these practices (Kane et al., 2018; Baker et al., 2021), the discussion is centered around these factors.

The content of this section proceeds as follows. First, we review reprocessing in relation to these three factors. Then we briefly explore remanufacturing or refurbishment; repair and maintenance; and redistribution. We conclude with a discussion of existing challenges to reusing devices.

5.1 Reprocessing

The most common way of recovery is through reprocessing, where biological material is removed from contaminated devices through the use of physical or chemical decontamination to ensure an already used device meets the requirements for safety and effectiveness for reuse (Kane et al., 2018; Kwakye et al., 2010). The Spaulding classification provides a useful tool for assessing which methods are appropriate to disinfect and reprocess a medical device. This classification system places medical devices into three categories based on hygiene criticality, the level of infection risk

associated with using the device on a patient (McDonnell & Burke, 2011). The classification system as well as the Canadian requirements for proper cleaning protocols (Health Canada, 2018; IPAC, 2018), is summarized in Figure 1 and Table 1.

Figure 1. Spaulding Classification

Critical devices

The first category consists of critical devices, such as syringes and surgical equipment, which enter the body and come into contact with blood or bodily fluids. Since these devices pose a high risk of infection if used again, they must undergo more aggressive and costly sterilization methods, in order to be suitable for reuse. Depending on the material composition of the device, this could involve steam sterilization (autoclaving) or gas plasma sterilization for heat-sensitive devices.

Semi-critical devices

Semi-critical devices do not enter the body, but come into contact with mucus membrane. They include laryngoscopes, respiratory equipment, and endoscopes, which require high-level disinfection using liquid chemical high-level disinfectants, thermal high-level disinfection, or pasteurization.

Non-critical devices

Lastly, blood pressure cuffs, face shields, gowns, stethoscopes, crutches, and patient furniture are examples of non-critical devices which do not enter the body. Low-level disinfection is appropriate, such as with alcohol-based disinfectants or sanitizing cloth wipes.

Table 1: Spaulding classification

Category	Definition	Required treatment	Examples of devices
Critical	Enter the body and come into contact with blood or bodily fluids	Steam sterilization or gas plasma sterilization	Surgical shavers
Semi-critical	Come into contact with mucus membrane	High-level disinfection (e.g., liquid chemical high-level disinfectants)	Laryngoscope, respiratory equipment, endoscopes
Non-critical	Do not enter the body	Low-level disinfection (e.g., alcohol-based disinfectants or sanitizing cloth wipes)	Blood pressure cuffs, stethoscopes, crutches, patient furniture, gowns

5.1.1 Environmental impact

Switching to reusables

The environmental advantage associated with switching from SUDs to reusables for other forms of medical devices is established in multiple studies. Within the OR, using reusable surgical instruments was identified as a promising strategy to achieve both economic and environmental savings in two systematic reviews on the carbon footprint of various surgical operations (Rizan et al., 2020b; Siu et al., 2017). Several life-cycle assessments (LCAs) have also shown significant waste and emissions reductions from replacing disposable blood pressure cuffs (Sanchez et al., 2020); vaginal specula (Donahue et al., 2020); laryngoscope handles and blades (Sherman et al., 2018); and laryngeal mask airways (Eckelman et al., 2012). For example, compared to using disposables, reusing laryngoscope handles and blades is estimated to cut down GHG emissions by a factor of 16 to 25 and 6 to 8, respectively (Sherman et al., 2018).

Amongst PPE, the environmental impact of reusable gowns is the most extensively documented. Reusable gowns usage is consistently recommended to curb medical waste during the pandemic (Rizan et al., 2021; Farrell & Smyth, 2021; Baker et al., 2020). They simply require laundering to be recovered and can be used between 75 to 100 times between washes (Baker et al., 2020). A recent LCA demonstrated how the use of reusable gowns over disposable gowns reduced natural resource energy consumption by 64%, greenhouse gas emissions by 66%, blue water consumption by 83%, and solid waste generation by 84% (Vozzolo et al., 2020).

Overcash (2012) found consistent environmental benefits across six LCAs on reusable gowns. Switching to reusable gowns was found to decrease natural resource energy use and carbon footprint by 200% to 300%; and decrease solid waste from 320 kg to 38 kg per 1000 gown uses. It is also reported that 65% of waste produced in the OR can be eliminated by using surgical drapes and gowns (Conrady et al., 2010).

Considerable reductions in environmental harms and costs from using reusable forms of PPE were predicted in two studies quantifying healthcare waste during the pandemic. In the United Kingdom, reusing gowns and face shields would have reduced the carbon footprint of PPE used by healthcare facilities during the first six months of the pandemic by 10% (Rizan et al., 2021). Moreover, switching to reusable gowns, as well as reusable aural speculums, and metallic tongue depressors would amount to the greatest reductions in plastic use at one outpatient ENT department (Farrell & Smyth, 2021).

Single-use versus reusables

Noteworthy, 95% of the carbon footprint from single-use PPE results from their production, transportation, and waste management (Rizan et al., 2021). Another study found that for single-use surgical materials (gowns, drapes, blue wrap, surgical instruments), the production and manufacturing accounts for 95% of the environmental impacts (Thiel et al., 2015). For SUDs, the

main driver of emissions arises from manufacturing, transportation, and waste management. However, this is not the case for reusable devices.

The sterilization of reusable devices requires steam, waste, and cleaning agents, which is the main driver of environmental impacts (Sherman & Hopf, 2018; Thiel et al., 2017; Leiden et al., 2020). Cleaning and sterilization processes can account for 90% of GHGs emitted for reusable surgical instrument set for spinal fusion surgeries (Leiden et al., 2020). Eckelman et al. (2012) found that for disposable laryngeal masks, the greatest source of GHG emissions is concentrated in the production of plastic polymers (60%) and incineration (15%). While for reusable laryngeal masks, it is washing and sterilization (77%). Similarly, the manufacturing of single-use ureteroscopes results in 86% of the carbon footprint, while sterilization for reusable ureteroscopes makes up 88% (Davis et al., 2018).

Therefore, it is important to incorporate lifecycle thinking and identify the major sources of emission for each type of device when minimizing the environmental impact. For non-critical devices such as reusable blood pressure cuffs, decontamination using disinfection wipes can generate significant waste (Sherman & Hopf, 2018; Sanchez et al., 2020). Efforts to minimize the impact of reprocessing for these devices should then concentrate on the avoidance of unnecessary sterilization and the overuse of wipes through proper decontamination protocols.

5.1.2 Costs

The lifetime cost of reusables is generally lower than SUDs (Sanchez et al., 2020). However, they are often cheaper to produce, making the initial cost often higher, posing a barrier to purchase (Miller, 2020). Cost savings are more immediately apparent when it comes to reprocessing, and it is this, rather than any environmental benefit, that generally drives the adoption of reprocessing (Kane et al., 2018). For instance, one US hospital saved $60,000 and 23,000 kg waste over a year from switching to reusable surgical gowns (Kwakye et al., 2011). After circulating 3.3 million reusable gowns over a three-year period, a second US hospital saw $1.1 million in savings with 297 tons of waste diverted (Practice Greenhealth, 2015). Reprocessing seven medical devices (deep vein thrombosis compression sleeve, pulse oximeter, ligasure, harmonic scalpel, endoscopic trocar, arthroscopic shaver, and scissor tip) led to a reduction in overall economic costs of $520,000 annually at another facility (Unger & Landis, 2016).

The costs associated with reprocessing surgical instruments was analyzed in two systematic reviews. Jacobs et al. (2008) reviewed the economic outcomes of reprocessing SUDs across nine studies and reported that reprocessing various types of surgical instruments led to a 49% reduction of direct costs. Siu et al. (2017) reviewed the costs associated with reusable versus disposable surgical sets. They found that for disposable devices, additional costs arise from treating waste from unopened surgical sets and maintaining a large inventory. For reusable devices, additional costs arise from disassembly, cleaning, repair, and replacement. Despite this,

disposable surgical sets for laparoscopic surgeries can cost 6.4 times greater than disposable sets, even when factoring in sterilization costs (Slater et al., 2009).

5.1.3 Safety

Reusable PPE

Reusable forms of PPE, including reusable gowns and elastomeric respirators are readily available, used, and considered safe alternatives to their disposable varieties (PHO, 2020). Evidence suggests that reusable gowns pose low contamination risk while exhibiting similar levels of comfort and safety as disposable ones (Overcash, 2012; Baker et al., 2020). Additionally, the gown ties and fasteners on reusable gowns are less easily damaged compared to disposable gowns (CDC, 2020). Given proper design standards, material selection, and user guidelines, it has been shown to be effective in infection control while providing a suitable environmental and cost friendly alternative (Klemes et al., 2020).

While reusable forms of PPE have been widely adopted, the reprocessing of single-use PPE currently remains a topic of exploration. For disposable gloves, there may be an opportunity to reuse gloves by rinsing them with antiseptic between uses (Chang, 2020). This is a reported practice at one Indian cataract surgery clinic, where gloves are sterilized up to 10 times between procedures (Thiel et al., 2017).

Reusable masks

Since the onset of the pandemic, a considerable number of opportunities to diversify reusable options for PPE have emerged. In October 2020, Dorma Filtration received approval from Health Canada to produce the first domestically designed and manufactured reusable N99-equivalent mask in Canada (CNW Telbec, 2020). This mask filters out 99% of airborne particles, is made up of recyclable components, and can replace up to 30 single-use N95 masks. The mask was designed by Canadian doctors in partnership with the National Research Council of Canada. Distribution has begun in hospitals in Quebec (Weldon, 2021). The innovative mask offers an environmental advantage by being both reusable and recyclable; and being locally manufactured in Canada. Precision ADM also developed a reusable N95-equivalent mask which can be used up to 30 times. The mask is locally manufactured in Manitoba and has been distributed for use in critical care, emergency and adult operating rooms across Winnipeg (Gerwing, 2021).

Single-use PPE

Although decontamination may be possible for medical masks, which are considered a low-risk medical device in Canada (Health Canada, 2020), it may compromise the filtering efficiency and fit

of single-use filtering facepiece respirators (FFRs) (PHO, 2020). Because of these safety implications and lack of research into the decontamination of single-use PPE, the reprocessing of single-use gowns, masks, and gloves is not recommended by public health bodies in Canada, outside of a public health emergency (PHO, 2020).

Decontamination of FFRs, such as N95 masks have been shown to inactivate respiratory viruses, including COVID-19 (PHO, 2020; National Research Council, n.d.). However, after a certain number of rounds of decontamination, masks begin to lose their physical integrity, making them unsafe to wear (Rowan & Laffey, 2020). Multiple methods to decontaminate medical masks have been explored, though there is a lack of both consensus on and evidence for which method works best (Sarkis-Onofre et al., 2020). A systematic review by Rodriguez-Martinez et al. (2020) and a scoping review by Sarkis-Onofre et al. (2020) on decontamination methods for disposable N95 respirators found that ultraviolet germicidal irradiation and vaporized hydrogen peroxide hold the most promise based on efficacy and maximum number of decontamination cycles. Treatment with heat has also been suggested, but more tests are needed to determine the efficacy of this method (Campos et al., 2020; Lensky et al., 2020).

Disinfection technologies for masks

In an early effort to respond to the shortage of N95 masks at the beginning of the pandemic, Québec City manufacturer, TSO3 developed the Sterizone VP4 using existing technology. The device uses vaporized hydrogen peroxide and ozone at a low temperature to sterilize and decontaminate masks up to 2 times after initial usage (Government of Canada, 2020). Researchers at the University of Guelph also relied on existing disinfection technologies for killing pathogens on fruits and vegetables using ultraviolet light, hydrogen peroxide, and ozone to develop a portable disinfection device that decontaminates N95 masks within 30 seconds (ENC, 2020; Mitacs, 2020). The device can also sanitize face shields, goggles and hospital gowns, and is being used by 70 healthcare institutions across Canada.

5.2 Remanufacturing or refurbishment

At the end of their life, some SUDs can be returned to the original device manufacturer, remanufactured back into a similar quality as its original form, and bought back at up to 70% off the original price (Leung et al., 2019; Kane et al., 2018). Refurbishment involves the same process, but refurbished items are lower quality than their original state (Kane et al., 2018). Activities include the de-installation of non-functional devices, inspection and replacement of non-functional parts, software upgrades, cosmetic changes, performance checking, and re-installation (Guzzo et al., 2020).

Two literature reviews on the CE in the healthcare sector found that remanufacturing is a widespread and well-regulated practice in the United States and Europe (Kane et al., 2018; Guzzo

et al., 2020). Both are leading consumers and producers of remanufactured medical devices. There was a lack of literature on remanufacturing SUDs, perhaps owing to the fact that it typically occurs for complex, non-critical, long-lasting devices such as large surgical equipment, anesthesia machines, and hospital furniture (Kane et al., 2018).

5.3 Repair and maintenance

Healthcare facilities often have service contracts with manufacturers or third parties to recover the function of a device through repair or prevent it from losing its function through maintenance strategies such as routine checkups or cleaning. Both strategies extend the product lifetime (Ertz & Patrick, 2020). For example, laundry services incorporate repair and maintenance strategies for reusable gowns. They routinely monitor the number of uses; condition of fabric; mend holes and rips; and replace fastening ties (CDC, 2021).

5.4 Redistribution

Mobile medical units and platforms for device circulation were also identified as two promising approaches to maximize the lifespan of devices and reduce production of new devices, in both a sustainable and cost-effective way for facilities and manufacturers (Guzzo et al., 2020).

The first approach involves the provision of short-term access to equipment through mobile medical units. Existing mobile units in the United States and Europe rent out large and expensive equipment to different facilities. This could be of particular interest for facilities with fluctuating demands for a specific procedure or wanting to expand.

Another strategy is third-party platforms for device circulation where facilities can share, rent, or sell previously owned medical devices. Guzzo et al. (2020) identified numerous buy and sell platforms which circulate all types of devices from high-value, non-critical equipment such as imaging equipment, and low-value, critical devices such as surgical scissors. Other services also sell spare parts and provide maintenance services to pre-owned medical equipment (Ertz & Patrick, 2020).

Device circulation platforms

Health-Share is a Canadian initiative which facilitates closed sharing online marketplaces for healthcare organizations to sell, rent, or swap medical devices and materials (Health-Share, 2021). Emerging from the COVID-19 pandemic, it seeks to build resilience in healthcare supply chains by matching excess supply with demand. It also includes options to advertise skills and staff, transport services, consulting and meeting rooms, parking spaces, and storage facilities.

Dotmed is another buy-and-sell platform which aims to maximize the lifespan of products and allow for facilities to source their own equipment, parts, and services (Dotmed, 2021). Healthcare facilities can advertise, and place offers to buy an assortment of medical supplies, including surgical instruments, laryngoscopes, patient furniture, and CT scanners. They also offer a virtual trade show where facilities can access specialized services to repair equipment and online equipment guides for popular models.

5.5 Challenges to reuse

Safety concerns

Increased use of SUPs is, in part, driven by concerns about infection control associated with improperly decontaminated reusable devices (Kane et al., 2018). During the COVID-19 pandemic, these concerns have become both more pressing and harder to address, leading to an increased preference for single-use PPE on behalf of healthcare professionals and the general public (Klemes et al., 2020).

An environmental scan conducted by Hailey et al. (2008) reported insufficient evidence to conclude the safety and effectiveness of SUD reprocessing. Given the mixed quality of the available studies, the authors were unable to support or rule out potential harm from reprocessing. Serious safety concerns are raised for medical devices with complex designs due to greater challenges in adequately reprocessing them and less available protocols (Kane et al., 2018). As previously mentioned, this is more apparent for devices with surfaces and components that are difficult to sterilize, such as intravenous catheters, tubing, and syringes. Furthermore, infections have been reported with the improper decontamination of more complex devices such as endoscopes and ureteroscopes (MacNeill et al., 2020).

Lack of evidence

It is difficult to obtain reliable information on infections from reusing devices due to the difficulties in studying the exposure of patients within controlled environments, resulting in a considerable lack of data (Hailey et al., 2008; Upadhyay et al., 2007).

Single-use forms of non-critical devices have become increasingly popular. The literature notes an absence of evidence to support the superiority of SUPs in terms of function and safety for disposable surgical instruments (Siu et al., 2017), blood pressure cuffs (Sanchez et al. 2020), dispoable gowns (Baker et al., 2020), and disposable laryngoscope handles (Sherman & Hopf, 2018). This point is further emphasized by a narrative review conducted by Sherman et al. (2020) who found that many infection control policies for SUDs are not founded on evidence of any advantage for risk reduction, resulting in increased waste generation. Consequently, they advocate for the re-evaluation of non-evidence-based infection control standards for some SUDs, and whether these devices should be sold as single-use.

In particular, blood pressure cuffs pose minimal risk to patients when decontaminated properly using disinfection wipes (Sanchez et al., 2020; Gialluly et al., 2006). Sherman & Hopf (2018) also question the appropriateness of single-use laryngoscope handles and tongue blades due to the limited evidence of a relationship between infection transmission and properly decontaminated devices. Similarly, the safety of reusable gowns is well-established in reducing cross-contamination (Baker et al., 2020). Re-treatment chemical solution is often added to the gown wash by laundry services to maintain durability and repellency (CDC, 2021). Training programs to support medical device processing are in place in Canada to ensure that on-site reprocessing of low risk SUPs meets infection prevention and control standards (CAMDR, 2018).

More complex SUD can also be re-processed, but must be re-manufactured by a commercial provider that assumes the role of equipment manufacturer for the purposes of market access regulation. This type of re-processing has been slow to develop in Canada, in part due to delays in the creation of a regulatory pathway by Health Canada. A review by Cowling & de Léséleuc (2015) on the state of re-processing SUDs in Canada found that there are few commercial single-use device reprocessors; it is predominately conducted off-site by third-party processors in the United States. Out of the pandemic, there are growing sentiments that more must be done to develop reprocessing standards and enforce adherence to current standards for PPE and medical devices (Hancock-Howard et al., 2021).

Tracking

A common misperception is that reusables are invariably environmentally preferable over SUPs (Miller, 2020). It is important to note that reusables only incur a lower environmental impact over multiple usages. This means they must be reused a certain number of times to offset the cost and environmental impact of producing them, after which they generate a smaller environmental impact than SUPs (Miller, 2020). Reusable gowns, for example, require more energy to initially manufacture than disposable gowns. When considering repeated usages across their entire lifespan, they use less energy, release less GHGs, and produce less waste than disposable gowns (Baker et al., 2020).

This makes tracking the number of times a reusable device is used a necessary component to ensure these environmental benefits are not lost. However, few studies discussed this conditionality. Eckelman et al. (2012) specified how reusable laryngeal masks must be reused to an optimal number before they can achieve lower costs than disposables. They discuss the need for inventory and operating procedures which enable these devices to be maximally used. Another study mentioned how these devices are often reused until there are visible signs of damage and disposed of without tracking the number of uses (Donahue et al., 2020). Only one study detailed the practice directly. Baker et al. (2020) described how laundry services track the number of washes for reusable gowns using a marked grid system.

Context of use

To determine how to optimally reuse a given device, consideration must be given to the context of use. For instance, Sanchez et al. (2020) studied the environmental and economic impacts of reusable and disposable blood pressure cuffs in multiple clinical settings. When reusable cuffs are shared amongst patients in in-patient care settings, they are more expensive and more wasteful than disposable cuffs. This is because the reusable cuffs must be disinfected between usages and the majority of emissions associated with using reusable cuffs emerge from disinfection wipes. Therefore, it was more cost and environmentally advantageous to use disposable cuffs in settings where they are shared amongst patients. However, when patients were assigned a dedicated blood pressure cuff used for the entirety of their admission, fewer wipes were used, resulting in it being more environmentally preferable than disposable cuffs.

6. Recycling

Healthcare generated waste can broadly be sorted into three categories: general waste, recyclables, and biomedical waste. About one-third of waste generated in Ontario hospitals is recyclable (30.2%), while biomedical waste represents a smaller portion (9.6%) (CCGHC, 2019). Waste audits in the OR have shown around 20% to 30% of waste is recyclable (Lee et al., 2002; McGain et al., 2015). Plastics make up over half of this recyclable waste (McGain et al., 2015).

Plastic is usually recovered through a process called mechanical recycling where a device is broken down into its individual components, which are then reconstituted into a useful application (Rhodes, 2019). For a product to be recycled, it must first be disposed of appropriately in a recycling receptable. Proper segregation of waste is crucial in healthcare facilities which produce many types of waste that require different treatments. After waste has been sorted, it is often transported to another facility to be decontaminated, segregated by polymer and color, and turned into pellets (Prata et al., 2019). Finally, it must be sold to manufacturing companies to be made into new products.

From a sustainability standpoint, priority should always be given to reducing waste and reusing products before considering recycling due to its smaller cost and environmental savings (Miller, 2020). For instance, recycling waste from laparoscopic surgeries was only estimated to reduce 5% of greenhouse gases, while a combination of reduction and reuse strategies led to reductions of 80% (Thiel et al., 2018). The effects of recycling are more considerable when done in large volumes across regions or healthcare systems (McGain et al., 2015).

In Canada, only 11% of total plastic waste is recycled, while the rest ends up being landfilled, incinerated, or littered (Environment and Climate Change Canada, 2018). The United Kingdom estimates only less than 5% of plastic waste generated in the NHS is recycled (Rizan et al., 2020a). Several challenges create the conditions for low recycling rates including inadequate recycling infrastructure, staff knowledge of waste management and safety concerns, product design, and a lack of profitable market.

In this section, we first discuss existing strategies to recycle SUPs in the medical device industry. We then focus on challenges to recycling medical waste and emerging opportunities that address these challenges.

6.1 Current state of recycling

Guzzo et al. (2020) reviewed several CE strategies employed by the medical device industry to reduce waste generation and the consumption of resources in healthcare. They identified two common circular business models for recycling medical devices: (1) end-of-life equipment collection; and (2) continued collection of disposables. The first strategy typically occurs for medium to high value, non-critical devices, such as imaging equipment of patient monitors. Recycling companies retrieve obsolete devices from healthcare facilities. They then harvest functional parts and recycle non-functional parts.

The second strategy is typically employed for low-value, high-critical SUPs made of polyvinyl chloride, such as intravenous bags, oxygen masks, and oxygen tubing waste, and sharps. The continued collection of disposables is proposed as a solution to manage the complexity of hospital waste. This occurs through take-back schemes where manufacturers of SUDs work with healthcare facilities to implement infrastructure to properly sort and collect discarded devices. These devices are then retrieved by the manufacturer to be recycled.

Both these practices may be financially advantageous for hospitals that receive reduced costs of disposal and for recycling companies that receive revenue from selling valuable parts and collecting plastic material. When done in large quantities, it has the potential to divert a significant amount of waste from ending up in landfill. For instance, Wormer et al. (2013) documented how efforts to recycle all SUDs used in the OR at one US hospital led to a reduction of 12,860 pounds of waste annually. They estimated if recycling of four SUDs (laparoscopic trocars, cautery, clip appliers, and energy devices) were to occur across the entire US healthcare system, $150 million

could be saved per year. By recycling pre-incision plastics instead of throwing them away, one clinic diverted more than 1 million pounds of plastic from landfills (Fox, 2019).

Recycling plastics in the healthcare sector

To manage plastic waste in the healthcare sector, Synergie Santé Environnement (SSE), a non-profit organization based in Quebec, Canada is conducting a pilot project with 5 to 7 hospitals to collect and recycle all health-care generated plastics (GGHH, n.d.). This includes blue wraps, IV tubes and bags, bottles, and more. In the past, SSE has assisted facilities in developing and implementing a plastic waste management program from sorting materials, collecting waste, packaging, storage, and transportation (SSE, 2019). The organization help identify ways to increase recovery rates while reducing operating costs throughout the process. They also assist with selling recovered plastic materials and packaging to industry partners.

6.2 Challenges and opportunities

McGain et al. (2015) conducted a waste audit of six ORs in Australia and found that plastics make up over half of all recyclable waste. However, almost half of the recyclable plastic waste was discarded into the general waste bin. This presents a missed opportunity for recycling SUPs within the OR. The literature notes several challenges and opportunities to increased recycling of hospital waste, which includes adequate infrastructure, staff knowledge and safety concerns, product design, and lack of a profitable market.

6.2.1 Adequate infrastructure

The amount of SUPs which end up being recycled depends on availability of facilities within healthcare units and jurisdictions (Rizan et al., 2020a). 30% of plastic waste comes from single-use syringes, intravenous bags, and tubing, which are typically made of polyvinyl chloride (Lee et al., 2002). Other types of plastic commonly found in medical SUPs include polyethylene, polypropylene, and co-polymers (Rizan et al., 2020a). Although technologies exist to recycle these polymers, they are costly and not readily available, making the existence of facilities a limiting factor (Harding et al., 2021). Additionally, within facilities there needs to be adequate physical space for waste receptacles and an efficient and easy to understand waste classification system (Wormer, 2013).

6.2.2 Staff knowledge & safety concerns

Education on proper sorting is essential for initiating successful recycling programs in healthcare facilities (Wormer et al., 2013; Rizan et al., 2020a). A recent Canadian survey reported only less

than a third of anaesthesiologists recycled at work, citing lack of awareness and education of recycling programs as a reported barrier (Petre & Malherbe, 2019). In another study, healthcare providers reported inadequate facilities, staff attitudes, and inadequate knowledge as major barriers to recycling (McGain et al., 2012). These factors can lead to waste being improperly sorted due to uncertainty about proper waste classifications or being overly cautious when disposing of waste. Healthcare workers are known to be overly cautious when disposing waste and may throw recyclable or general waste into regulated waste streams due to concerns of contamination (Kane et al., 2018). This is a problem since improper segregation results in more waste being incinerated than needs to be, leading to the release of more GHGs and subsequent costs associated with treatment. Disposing of biomedical waste can be up to eight times higher than general waste disposal (Donmez et al., 2019).

As a result, safety concerns surrounding potentially infectious waste is another specific challenge with recycling hospital waste (Kane et al., 2018). This was evident in the past year where concerns about biohazardous contamination have halted global recycling efforts of SUPs over the potential risk of COVID-19 contamination, making landfilling and incineration preferred methods for disposing of medical waste (Patrício Silva et al., 2021; Haque et al., 2021). McGain et al. (2015) found no evidence of infectious contamination from recycling in the OR. Additionally, biomedical waste only makes a small fraction of waste generated in the hospital (9.6%) (CCGHC, 2019).

Providing education to healthcare workers on how to properly sort general waste, biomedical waste, and recyclables has been shown to be effective in increasing recycling rates (Wormer et al., 2013). It has the potential to reduce the amount of waste that inappropriately ends up in general or biomedical waste streams, which is estimated to lead to the greatest cost savings related to waste disposal in the OR (Kagoma et al., 2012). Proper safety protocols, training, and staff education are necessary to enable increased recycling in healthcare facilities.

6.2.3 Product design

Mixed plastics

SUPs that are made of mixed plastics pose a challenge to mechanical recycling, since it diminishes the durability and quality of the recycled product (Rhodes, 2019). This is evident in single-use face masks, such as blue surgical masks and FFP2 type masks which are typically composed of different layers and a mix of plastics. Rodriguez et al. (2021) conducted a LCA comparison on these types of masks and found that their design increases their environmental burden. They suggest using only a single type of plastic, such as polypropylene to decrease their environmental load. Manufacturers must ensure that they combine chemically compatible sources which abide by local recycling regulations (Leissner & Ryan-Fogarty, 2019).

Currently, chemical recycling is proposed as a way to manage mixed plastic waste (Parashar & Hait, 2021). One method is through catalytic pyrolysis, which can turn plastics into gases similar to gasoline (Rhodes, 2019). This form of recovery is advantageous as it recovers energy from waste and there is no need to separate into polymers.

One of the challenges with chemical recycling is that it is energy intensive (Prata et al., 2019). Mechanical recycling also generates emissions from collection, treating contaminated devices, and manufacturing products (Rhodes, 2019). Wyssusek et al. (2019) identifies the need for LCAs to determine the environmental impacts of recycling particular devices and ensure that recycling a certain SUPs is able to offset the environmental impact from recycling it.

Easy disassembly

Many devices are not built to be easily disassembled into individual constituents, making them not easily recyclable (De Decker, 2018). Rodriguez et al. (2021) suggest that single-use masks must be designed to be easily disassembled into separate components to enable recycling. For surgical masks, this means that the aluminum wire and bands need to be designed to be easily removed. This also helps healthcare workers who may run into challenges when recycling devices with multiple components which require disassembly. A case study showed that healthcare workers found it challenging to identify proper disposal for the individual components of a single-use infant formula bottle due to labelling issues (Leissner & Ryan-Fogarty, 2019).

6.2.4 Lack of a profitable market

A suggested strategy to reduce PPE-related waste generated in the pandemic is to incorporate discarded masks in construction applications. Kilmartin-Lyn et al. (2021) found that when used surgical masks were added to concrete it improved its strength and quality. Sabarian et al. (2021) included shredded face masks into pavement base applications and found it improved ductility, flexibility, and strength. Other applications of discarded PPE include turning the leftover ash from incineration into filler in asphalt and brick (Green Circle Salons, 2019). Other forms of plastic waste have also been turned into asphalt or construction materials (De Decker, 2018).

Although these are innovative methods to manage waste, these are exemplary of "downcycling," where materials are recycled into lower quality products, which eventually enter the waste stream again (De Decker, 2018). It also occurs for stainless steel laryngoscope handles which are often recycled into low quality carbon steel (Sherman & Hopf, 2018).

Recycled products are generally lower quality, and more expensive to manufacture than products made of virgin plastic materials (Rhodes, 2019). Therefore, it is more cost-effective for companies to manufacture new products made from virgin plastics than go through the laborious, costly route of using recycled materials (Prata et al., 2019). As a result, there is a lack of profitable recycling market and few recyclers (Leissner & Ryan-Fogarty, 2019).

PPE Recycling Initiatives

There have been also some industry-led PPE recycling initiatives in Canada. In February 2021, British Columbia mask manufacturer Vitacore launched the first Canadian recycling program for single-use masks and respirators in Vancouver (CNW, 2021a). As part of this program, recycling bins are provided to long-term care and urgent care facilities where workers can dispose of single-use face masks. The masks are collected and sterilized by Vitacore before being sent to McMaster University for mechanical separation and re-pelletization into construction materials used to reinforce concrete.

Recycling company Terracycle has also responded to the rising demand for unavailable PPE recycling through their recycling service, the Zero Waste Box (Terracycle, 2021). Terracycle stores and sorts the PPE waste, which is then sent to a third-party processor to be mechanically separated. Polypropylene from the masks is re-processed into raw materials used in plastic lumbar and composite decking. Gloves are turned into flooring tiles and playground surface covers.

7. System Redesign

Reducing, reusing, and recycling are key principles in achieving a sustainable approach to reducing hospital-generated PPE and SUPs waste. Beyond these principles, there is also a need to re-think consumption patterns, industry behaviour, and the design of products to further minimize waste (Geisendorf & Pietrulla, 2018). As depicted in Figure 2, the pathway to achieving a CE within the medical device industry involves five returning loops with a hierarchal order of value. The top priority within the CE is to optimize usage through reducing waste and reusing SUPs. This decreases demand and production of a product, resulting in fewer virgin resources being extracted; fewer devices being manufactured and transported; and fewer devices ending up in landfills or requiring treatment. It also involves shifting business models which promote circularity; remanufacturing or refurbishment; parts recovery; and recycling.

The pathway for a successful transition to CE in the healthcare sector requires the involvement of hospitals, policymakers, and manufacturers (MacNeill et al., 2020). A discussion of the roles of these stakeholders is presented here.

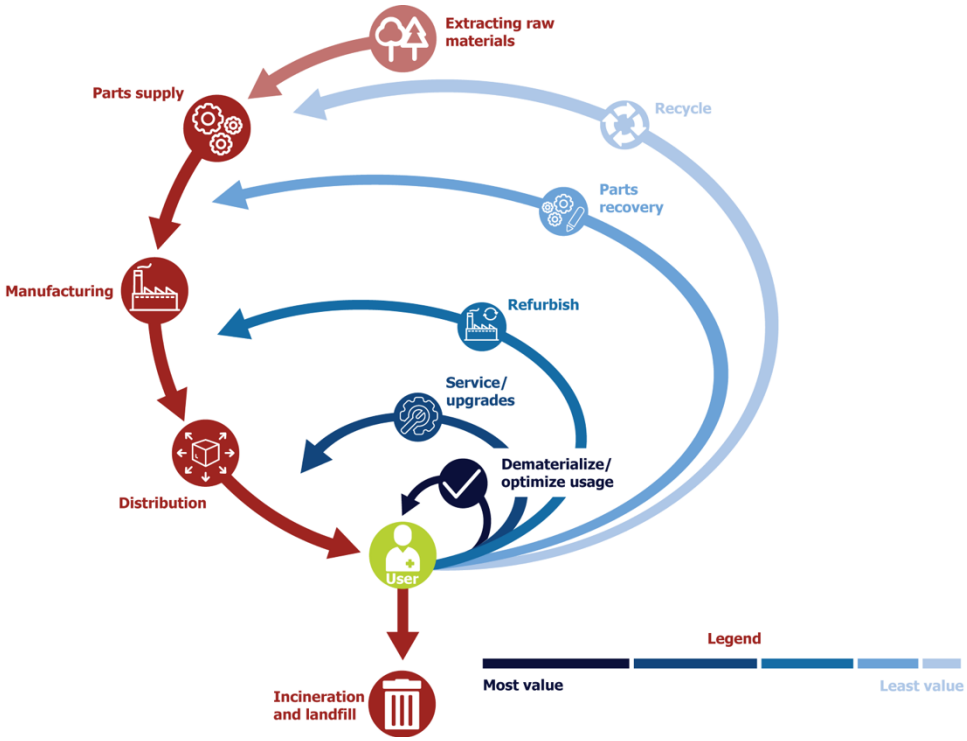

Figure 2 depicts the processes to achieving a CE within the medical device industry. It was developed through a collaboration between Health Care Without Harm Europe and medical technology manufacturer Philips. The red pathway represents the linear economy, where raw materials are first extracted, parts are supplied, the device is manufactured, distributed to the user, then incinerated and landfilled. The move towards the CE can be achieved through these five returning loops with a hierarchal order of value. Dematerializing and optimizing usage through reducing or reusing waste holds the most value. This reduces demand and production of a product. Shifting business models to sell services and upgrades; and refurbishment are also identified as key approaches. When a device can no longer be refurbished, functional parts can be recovered to be manufactured into new products or it can be recycled.

7.1 Role of hospitals: Sustainable procurement

Healthcare facilities can choose sustainable procurement, where they purchase products or services from manufacturers who are able to demonstrate lower environmental impacts (Kwakye et al., 2011). It is recommended by numerous authors as a way the healthcare sector can actively address escalating environmental harms associated with the provision of healthcare (Eckelman et al., 2012; Sherman & Hopf, 2018; Kwakye et al., 2011; Leissner & Ryan-Fogarty, 2019; Guzzo et al., 2020; MacNeill et al., 2020; Ritchie et al., 2021). Given that there is no legal motivation or incentive for manufacturers to make reusable devices, the healthcare sector could play a role in this push by updating procurement policies to favor using reusables (MacNeill et al., 2020). This could push innovation amongst manufacturers and drive them to adopt more sustainable practices. There is also potential to re-think waste disposal sorting practices to ensure the appropriate segregation of plastic for recycling through an easy-to-use recycling program, involving waste vendors and hospital staff (Leissner & Ryan-Fogarty, 2019).

Waste Management Regulations

In Canada, there is an opportunity to update institutional practices to allow for recycling of empty pharmaceutical containers and syringes without needles in healthcare settings to achieve greater sustainability across all jurisdictions.

A targeted grey literature scan of jurisdictional guidance on managing hospital waste showed that only two provinces (Alberta and Newfoundland & Labrador) have policies on how empty medication containers or vials can be disposed of in general waste streams (see Appendix B for a summary of methods and findings). While recent amendments to the Resource Conservation and Recovery Act in the United States designate empty containers, syringes, and IV bags as general waste (EPA, 2019), in Canadian jurisdictions, there is a lack of specification on how empty containers should be treated. Similarly, the regulations on recycling syringes *without* needles is inconsistent across Canada.

Although there is a lack of specification from provincial regulatory bodies on how empty pharmaceutical containers and syringes without needles can be discarded, healthcare institutions may specify additional waste management regulations. For example, Alberta Health Services allows for the recycling of empty medicine bottles and containers (all kinds, except those used for hazardous – cytotoxic drugs) and empty, needleless syringes used in the preparation of non-cytotoxic, non- biohazardous medications (Alberta Health Services, 2015).

7.2 Role of policymakers: Shifting business models

Current regulations incentivize device manufacturers to produce SUDs, encouraging the profit-driven linear business model in the medical device industry. The decision of whether a device should be labelled as single-use or reusable is the responsibility of device manufacturers in the United States, Canada, and Europe. In the United States, for a device to be labelled and sold as "reusable," the manufacturer must demonstrate the safety of reprocessing a device, however these requirements do not exist for SUDs (MacNeill, 2020). Similarly, in Canada and Europe, device manufacturers oversee the labelling of their product. Manufacturers of reusable devices must validate that a device can be sold as reusable and provide information on cleaning and sterilization of the product, but the same requirements do not exist for single-use devices (Cowling & de Léséleuc, 2015; Ponchon & Pioche, 2017). Therefore, these manufacturers take on the added responsibility and finances to demonstrate the efficacy of the device. This makes it effectively easier for industry to get approval for a device as single-use than reusable, creating a regulatory incentive for manufacturers to create SUDs. There is also a lack of guidance for developing reusable PPE and a lack of standards for reprocessing single-use FFRs (Hancock-Howard et al., 2021).

Additionally, Canadian device manufacturers are not legally required to incorporate recycled materials in the manufacturing of new goods (Environmental Defence, 2018). It is much cheaper to create new plastic products from virgin resources and send them to the landfill compared to collecting and recycling plastic waste. More can be done to financially incentivize manufacturers to implement the CE. The lack of regulations which integrate waste management policies into business models is identified as a barrier to transitioning to the CE (Syberg et al., 2021). The European Union establishes requirements for certain plastic products, but widespread legislation directed at medical devices which facilitate CE business models such as servitization and extended producer responsibility (EPR) is needed (Singh et al., 2020).

Servitization

Servitization and EPR incentivizes manufacturers to focus on designing products that are durable and long-lasting, fostering innovation, circular product design, and maximal usage of resources (MacNeill et al., 2020). Guzzo et al. (2020) identifies servitization as an increasingly popular business model within the medical device industry where products are sold as a service. Here, healthcare facilities do not take ownership of products, instead manufacturers are fully responsible for the product throughout its lifetime. Manufacturers provide access to equipment through short-term or long-term renting and leasing contracts, while also providing continuous maintenance and remanufacturing services. This has been used for imaging equipment, processing equipment, OR equipment, and reusable medical gowns. Facilities benefit from entering customizable service contracts for equipment to receive preventative and maintenance services. In addition to providing access to devices, they provide spare parts, training to staff, remote repair and monitoring services, and equipment updates. Servitization has been demonstrated to prolong the lifetime of products, increase revenue for manufacturers, decrease costs for facilities, and reduce environmental impacts (Fargnoli et al., 2018).

EPR

EPR is a business model which shifts the responsibility of end-of-life management of discarded products and packaging from healthcare facilities to manufacturers. Manufacturers are responsible for the collection, reuse, and recycling of their products. Current provincial EPR initiatives in Canada for municipal plastic waste (e.g., plastic beverage containers) have been shown to reduce SUP waste and incentivize SUP waste recovery (Diggle & Walker, 2020). It is recommended that governments set collection and diversion targets for businesses, in an effort to encourage businesses to find innovative ways to make their products recyclable or provide collection programs (Environmental Defence, 2018). Regulations which dissuade manufacturers from using mixed plastics; and declare environment emissions of products to encourage LCA verification and cost-effectiveness analyses are also necessary (MacNeill et al., 2020).

Shortened supply chains

The CE model is identified as a way to achieve future resilience for the healthcare system and their supply chains (Wuyts et al., 2020). Notably, the shortages of PPE throughout the COVID-19 pandemic demonstrated the need for localized supply chains (Wuyts et al., 2020; Nandi et al., 2021; Sharma et al., 2020) and sourcing supplies with consideration to long-term resilience (e.g., diversifying the options for reusable products) (Miller et al., 2021). Reusable gowns, for example, are described as one way that COVID-19 solutions can also be climate solutions, due to how their use is associated with less waste and improved supply chain resilience (Baker et al., 2020).

Domestic manufacturing from local supplies is also suggested as one way to increase resilience in the medical devices supply chain (Miller et al., 2020). Local manufacturing also reduces the need for air freight to transport goods and could reduce 12% of carbon emissions associated with use of PPE (Rizan et al., 2021).

In March 2020, the Government of Canada announced Canada's "Plan to Mobilize Industry to fight COVID-19" in March 2020, which built capacity for Canadian businesses and manufacturers to assist in meeting Canada's demands for PPE. This was done by scaling up local production and re-tooling manufacturing lines to develop PPE, diagnostic and testing products, and sanitization products (Prime Minister of Canada, 2020). For example, uniform manufacturer Logistik Unicorp in Saint-Jean-sur-Richelieu, Quebec began supplying millions of medical-grade gowns, while automotive companies GM Canada and Unifor in Ontario began manufacturing medical grade surgical masks. Various other domestic suppliers have also ramped up efforts including Bauer (shifting from hockey skates to face shields); and outerwear clothing manufacturer WUXLY (shifting production towards reusable medical gowns) (Public Services and Procurement Canada, 2021).

In March 2021, Maitri Health Technologies received approval from Health Canada to begin domestically manufacturing their N95 medical-grade protective mask in Port Coquitlam, British Columbia (CNW, 2021d). Canadian companies Sterling Industries and Molded Precision Components also designed and patented a Shield-U face shield. 11 million have been purchased by the Government of Ontario (Medical Innovation Park, 2020). Though many of these examples of domestic production feature single-use products, shortening supply chains has the potential to dramatically reduce the environmental impacts associated with the production and transportation of medical products.

7.3 Role of manufacturers: Product re-design

Device manufacturers play an important role in supporting the reuse and recycling of SUPs through adopting circular design principles (Kane et al., 2018). Reusable devices must be designed to be durable for repeated usages and to survive mechanical or chemical damage. Additionally, certain design aspects such as sharp edges, crevices, and joints may make it difficult to sterilize. To support remanufacturing & refurbishment, they must be designed to be easily dissembled and easily cleaned.

Biodegradable masks

Redesigning single-use masks, gloves, and other disposable plastics with bio-based and biodegradable or compostable materials is identified as a key solution to optimizing waste management (Patrício Silva et al., 2020). With the help of $3.3-million in funding from the Government of Canada, FPInnovations has developed non-medical biodegradable single-use masks to reduce non-biodegradable waste (CNW, 2021c). Their three-ply biodegradable mask is made of sustainably produced Canadian forest fibre and biodegradable bioplastic. They can be disposed of as compost depending on local guidelines. In February 2021, NEXE Innovations also began development on a compostable disposable facemask in collaboration with University of British Columbia and Surrey Biofuels Facility (CNW, 2021b). Through this project they hope to create more partnerships between leaders in healthcare, manufacturing, and material science to develop technologies that reduce plastic waste.

There are growing calls for manufacturers to incorporate sustainability into product design, notably through adopting a life cycle approach to product development (Leiden et al., 2020; Leissner & Ryan-Fogarty, 2019; Moultrie et al., 2016; Sousa et al., 2020). In this way, the environmental impacts of a device are considered from conception to end-of-life. More specifically, this involves consideration of material selection (sourcing of raw materials), manufacturing (energy consumption and waste produced), distribution (packaging and transportation), use, and end-of-life processes (reuse, disassembly, recyclability) (Moultrie et al., 2016). This has informed efforts to reduce the packaging of products; reduce product mass and volume; and balance environmental and economic needs (Sousa et al., 2020). Sherman et al. (2020) also recommends a life-cycle inventory database for medical devices which would assist with sustainable procurement and the development of evidence-based best practices.

Hybrid medical devices

Hybrid products, a mix of reusable and disposable components, have been proposed as an alternative solution to SUDs (Kane et al., 2018). Hanson & Hitchcock (2009) demonstrated how a life-cycle assessment can be used during the design of a hybrid disposable-reusable dialysis cartridge to reduce the amount of material while maintaining functionality. They were able to reduce the weight of the device by 17% (preventing 560 metric tons of carbon dioxide and 6.1 metric tons of methane being emitted from incineration). The authors recommend hybrid disposable-reusable devices as an option to mitigate infection by making the largest part of the device (that does not come into contact with the patient) reusable.

8. Conclusion

Given the effects of healthcare generated waste on human health, the environment, and costs, the healthcare sector has an ever-growing responsibility to make practices more sustainable (Kagoma et al., 2012). Waste hierarchy principles have been effectively applied in a number of reduce, reuse, and recycling SUPs initiatives, generating significant cost savings and environmental benefits without compromise to safety. There are also many opportunities emerging from the pandemic to mitigate the environmental impact of PPE through diversifying reusable options, experimenting with decontamination methods, and establishing recycling initiatives. As global consumption of PPE and other SUPs are expected to grow (Rizan et al., 2020a), the need for an alternative solution to the linear model of producing, using, and disposing, has become crucial for protecting environmental and public health. Taken together with general principles of sustainable healthcare, the circular economy model has potential to contribute to building a sustainable health system.

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Appendix A

Project Description

Under Environment and Climate Change Canada's Plastics Initiative, the Canadian Coalition for Green Health Care (CCGHC) is investigating the health sector's contribution to plastic pollution through its use of disposable personal protective equipment (PPE) and other medical single use plastic (SUP) products. The project consists of two components: (1) a waste audit aimed at quantifying the amount of plastic waste produced by hospitals, in collaboration with University Health Network (UHN) and Vancouver Coastal Health (VCH); and (2) a test ideas to assess the potential to divert this waste stream to reduction and/or reuse.

Sub-Project Description

This report has been produced by the Centre for Sustainable Health Systems as a supplement to the main project activities (described above). The report reviews the major sources of PPE and SUP product waste in hospitals and offers an overview of current disposal practices, including recycling, as well as the factors known to influence these practices. The potential for reduction and reuse is also explored as these are necessary components of a comprehensive plan to reduce plastic waste.

The focus of this review is plastic medical products produced for single use (i.e., petroleum-based, non-biodegradable polymers). While the vast majority of these products are treated as general household waste and landfilled, some proportion is at risk of biocontamination and is therefore treated as biomedical solid waste (either disinfected for landfill or incinerated).

Specific medical products of interest:

- Disposable PPE that is mainly composed of polyolefins. This includes conventional disposable surgical masks, disposable respirators (e.g., N95), disposable surgical or isolation gowns, disposable drapes and disposable bedsheets.
- Medical plastic consumables such as gloves, syringes, and IV tubing
- Single-use medical devices such as laryngeal masks, laparoscopic devices

Specific deliverables of sub-project:

- A review of the academic literature on PPE and other medical SUP recycling, reuse and reduction opportunities (and factors conditioning these opportunities)

Appendix B

Purpose

In a separate review conducted by the authors, they sought to identify state regulation and guidance across Canada and in comparator jurisdictions for the management of biomedical waste for four types of hospital waste: empty drug containers, blood-saturated items, sharps, and pharmaceutical waste. For the purposes of this rapid review, we reported the results of empty drug containers and sharps only (as these are SUPs).

Methods

In April 2021, we conducted targeted grey literature scans for biomedical waste management policies in Canadian jurisdictions using government websites and provincial public health bodies. Literature was identified using the following keywords: (biomedical waste management in "jurisdiction"). Additionally, representatives on the Canadian Council of Ministers of the Environment's Waste Reduction and Recovery Committee were contacted. They were asked to provide information on available guidance in their province or territory on how to manage biomedical waste. We were able to gather information for all jurisdictions except Nunavut because at the time of search, the Department of Environment was in the process of reviewing and updating current guidelines on biomedical and pharmaceutical waste management. For these reasons, Nunavut was not included in this review.

Results

The results for empty drug containers and sharps without needles are summarized in the following table.

Jurisdiction	Relevant Regulation	Is there provincial guidance on…?		Is the guidance pro-environmental?	Comments
		Empty drug containers	Sharps without needles		
Alberta	Disposal of biomedical waste : acceptable industry practices (2019)	No	No	No	There is no specific guidance. Waste is managed according to regional infection control procedures developed by

					the institution responsible for the waste, and in compliance with the requirements of Alberta Health Services
British Columbia	Hazardous Waste Regulation (2017)	No	No	No	
Manitoba	Hazardous Waste Regulation-The Dangerous Goods Handling and Transportation Act (2015)	No	No	No	No specific provincial guidance found. Biomedical waste from hospitals would be legislated under hazardous waste legislation
New Brunswick	Clean Environment Act, Water Quality Regulation (2012)	No	No	No	Hazardous waste is managed through the Clean Environment Act, Water Quality Regulation considering hazardous waste as a contaminant
Newfoundland & Labrador	Management of Biomedical and Pharmaceutical Waste (2016)	Yes - Empty medication containers or vials, empty	Yes- Syringes without needles are exempted from being	Yes	

		capsules, empty bottles (containing no liquid) are exempted from being regulated as biomedical waste	regulated as biomedical waste		
Northwest Territories	Guidelines for the Management of Biomedical Waste in the Northwest Territories (2005)	No	No	No	
Nova Scotia	Dangerous Goods Management Regulations (2017)	No	No	No	
Nunavut	Not included in this review. At the time of search, they were in the process of reviewing and updating current guidelines.				
Ontario	C-4: The Management Of Biomedical Waste In Ontario (2016)	No	No	No	
PEI	Environmental Protection Act Waste Resource Management Regulations (2019)	No	No	No	
Québec	Environment Quality Act - Regulation respecting biomedical waste (2020)	No	No	No	

Saskatchewan	Saskatchewan Biomedical Waste Management Guidelines (2008)	No	No	No	
Yukon	Guidelines for the management of biomedical waste in Yukon (2018)	No	No	No	